CHAPTER 22

Artificial Cassava Drying Systems

Lisímaco Alonso[1], Miguel Angel Viera[2], Rupert Best[3], Sonia Gallego[4], and José Alberto García[5]

Introduction

Great potential exists in tropical Latin America for using dried cassava in animal feed. Good prospects also exist for including it in human food as a source of calories in processed foodstuffs, together with other raw materials. Examples include composite flours for soups, beverages, breads, and pastas. These end uses have created a need to develop drying methods that are efficient, reliable in terms of product quality, and technically and economically feasible. These three aspects in the dried cassava production should be considered within the socioeconomic situation of the developing countries that produce cassava.

Among the different drying systems there are two that require relatively low investment and are simple to manage. They therefore create interest, and have been included in CIAT's research programs. The two systems are *natural drying* and *artificial fixed-bed drying*.

Technology 1:

Case Study of Artificial Cassava Drying in the Colombian Atlantic Coast[6]

Lisímaco Alonso, Miguel Angel Viera, and Rupert Best

In the 1970s, CIAT adapted a technology to naturally dry cassava and applied it on a commercial scale in the Colombian Atlantic Coast in a collaborative project with the Fund for Integrated Rural Development (DRI, its Spanish acronym)[7]. The project was directed towards establishing small rural businesses that produced dried cassava for animal feed. In 2000, more than 180 cassava drying plants were established in Colombia.

Natural drying depends completely on climatic conditions, which restricts its use during rainy seasons. Thus, to prolong the drying period and ensure continuous supplies of dried cassava, a fixed-bed dryer with artificial circulation of hot air was chosen. This system was evaluated, using different sources of heat such as diesel, propane gas, coal, and a solar collector.

In this chapter, the results of this evaluation are presented and the usefulness of artificial drying discussed for the current conditions of cassava production and marketing in the Colombian Atlantic Coast. This method is also studied as an alternative in the production of dried cassava for human consumption.

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6. The text of this section of the chapter, written by L. Alonso, M.A. Viera, and R. Best, was published in Revista ACOGRANOS (Colombia), no. 3, 1987.
7. For an explanation of this and other acronyms and abbreviations, see *Appendix 1: Acronyms, Abbreviations, and Technical Terminology*, this volume.

Research history

The most economical drying method that humans have used since remote times is natural drying. This method of drying cassava was studied by several researchers, using both concrete floors and vertical or sloping trays during the 1970s (Roa 1974; Best 1978; Thanh et al. 1979). These studies led to better understanding of the factors most affecting the process such as the size and shape of cassava chips, load density, and environmental conditions.

Despite the best efforts to improve natural drying techniques and the advantages that these offer over artificial drying in terms of investment and operational costs, they cannot be used in regions where environmental conditions are unfavorable. For these areas, the use of batch dryers, involving the circulation of ambient or hot air or a combination of both, directly through a layer or fixed bed carrying the product to be dried. The use of continuous artificial dryers of large capacity is economically the most favorable alternative for Latin America (Crown 1981; Freivalds 1982).

In parallel to research on natural drying, studies on fixed-bed drying were carried out to improve operational parameters, bed height, and air temperature and speed for drying cassava chips.

- Chirife and Cachero (1970) found that beds of up to 12 cm high do not appreciably reduce drying time with air flows at more than 5000 kg/h per m^2. The temperature at which chips are toasted to low moisture content (<35%) is more than 84 °C. These authors also found that constant speed was not present and that the internal movement of moisture within the chips is the mechanism that controls the process from the beginning. These findings were later confirmed by Webb and Gill (1974) and Akhtar (1978).

- On a larger scale, Rossi and Roa (1980) and Ospina (1980) experimented with a dryer that had a 15-m^2 drying area and was coupled to a solar collector with 100 m^2 of absorbent area. The authors used mathematical models to determine the minimum air flow that should be applied as temperature and relative humidity vary. They reported that, for 30-cm-high beds, the applied flow ranged between 47.5 and 102.5 m^3/min per ton of cassava chips, with air temperatures ranging between 20 and 40 °C, and relative humidity between 25% and 55%.

- Toh (1973) studied the drying of grated cassava pulp at several temperatures, air flows, and load densities in a continuous tunnel dryer. Pulp had been dried previously to a moisture content of 50% (wet basis) in a filter press. A kerosene burner was used to heat the air. Fuel consumption varied exponentially with load density, and increased (to a lesser extent) when flow was increased. Toh found that, for the experimental conditions, heating air to temperatures of more than 70 °C was unsuitable because of high fuel consumption.

- With this same material (pressed grated pulp), Seng (1976) evaluated the use of a rotary and continuous dryer. The fuel used accounted for 55% of the operation's total cost. Even so, this system could compete, in terms of costs, with traditional sun drying under Malaysian conditions, where the study was developed.

- A study on the economic feasibility of establishing an artificial drying plant for dried cassava chips was carried out by the National Center for Food Science and Technology (CITA, its Spanish acronym) in 1974, in Costa Rica. The project was found feasible, with returns of 11% on the total investment and 16% on the fixed investment, if the plant was operated at a minimum capacity of 10 t/ha for 20 h per day and 200 days per year. Based on this study, a plant was installed, but it failed because of poor location and the inability of the area to supply the necessary raw material.

The studies mentioned above indicate that, when attempting to minimize operating costs and obtain good quality dried cassava, control parameters are fineness of chipping the material, temperature, and air flow. Furthermore, to ensure the feasibility of the process, a continuous and adequate supply of raw material must be guaranteed.

Research CIAT plan

Our study in Colombia was carried out in two phases:

- *First*, a 6-m^2 dryer, coupled to a flat solar collector with a 30-m^2 surface, was evaluated. The dryer and collector were constructed in the Municipality of San Juan de Betulia, Department of Sucre, in a region known as the Colombian Atlantic Coast.

- *Second*, at CIAT (Palmira, Department of Valle del Cauca, southern Colombia), two dryers were used. One had 2 m^2 of drying area and was coupled to a coal burner. The other dryer had 6 m^2 and was coupled, independently, to two burners, one of propane gas and the other of diesel.

To evaluate the dryers with the three sources of heat, the quantity of chips placed in them was modified to obtain different air flows per ton of fresh cassava chips. Air temperature was reduced to the values obtained with the solar collector and was set at 50 and 60 °C for the two fuels used.

Raw materials

Roots were harvested from cassava (*Manihot esculenta* Crantz) crops that were 8 to 10 months old. The varieties used were, for the first phase, the local 'Venezolana', planted in the Atlantic Coast, and, for the second phase, 'Manihoica P-12', a variety planted at CIAT.

Cassava roots were chipped in a machine prototype, known as "Thailand" type. It consisted of a metal structure with a feed hopper and a vertical turning disk. The disk had six rows of holes with diameters of about 25 mm (Figure 22-1), and sliced the cassava into chips that measured 60 to 80 mm long, 25 to 30 mm wide, and 7 to 10 mm thick. These standard chips were produced at a rate of 42%, together with smaller chips (at 34%), and fine particles (at 24%).

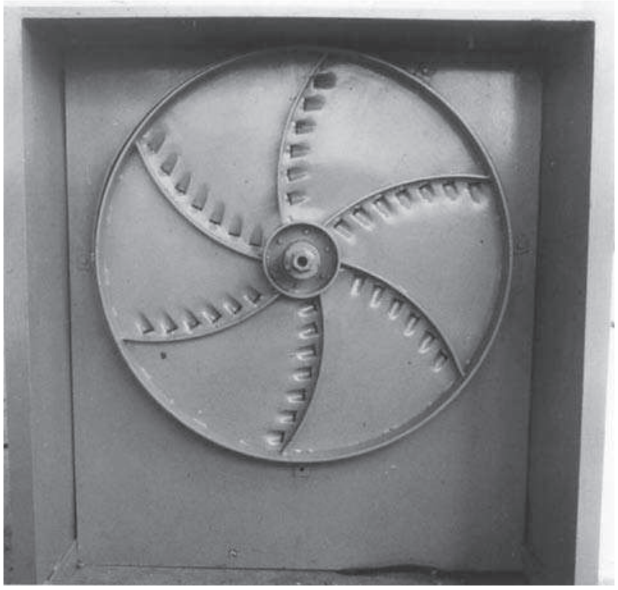

Figure 22-1. Cassava chipping machine of the type "Thailand".

Drying systems

First phase. For trials in the first phase, the system shown in Figure 22-2 was used. It consisted of a 6-m^2 dryer, with a centrifugal fan and a 30-m^2, flat, solar collector. The dryer was a chamber constructed from materials available in the region. It measured 3 m long by 2 m wide. The drying area was a false floor formed of galvanized steel sheets, which were perforated with 3-mm-diameter holes for 3% of their total area. The sheets, measuring 1 × 2 m, were supported 60 cm off the ground by wooden beams.

A Dayton fan (reference no. 3CO73) circulated the air through the system by means of blades that curved backwards. The machine was operated by a 1-hp electric motor.

The solar collector had a 30-m^2 absorbent surface. It was constructed on a 6-cm-thick concrete floor edged with concrete blocks. The medium used for absorbing solar radiation consisted of corrugated zinc sheets painted in matte black. These sheets were placed inside the collector, between the floor and a plastic cover (caliber 6), itself supported by a structure of wood and chicken mesh (Figure 22-2).

Second phase. This phase of the experiment was carried out at CIAT, where two dryers were used. The one with a 2-m^2 drying area was coupled, through a Dayton centrifugal fan (reference no. 3CO73), to a unit comprising a coal burner and heat exchanger (Figure 22-3). The coal burner for the air oven was basically a combustion chamber or housing with a stationary grill. The heat exchanger was a double concentric tube, with longitudinal blades on both sides

Figure 22-2. The solar collector used to heat air for a cassava chip dryer.

Figure 22-3. An artificial fixed-bed dryer that uses a coal burner to heat the air.

of the interior tube by which the combustion gases flowed. The drying air circulated through the annular space formed by the two tubes.

The 6-m^2 dryer was coupled independently to two heating units, one of propane gas and the other of diesel. The diesel unit consisted of a Lister 7.5-hp motor (model LT1), coupled directly to a Lister axial fan. Through a transmission belt, the unit ran a Markon generator, producing an electric current of 1.5 kilovolt-amperes (kVA), which provided the current needed to operate the diesel burner (Nu-way Benson). The propane gas unit (Farm Fans, model 116SH) consisted of an axial fan and gas burner. Figures 22-4 and 22-5 show the heating units (diesel and gas) that were coupled to the dryer.

The coal and diesel burners heated the air indirectly, that is, they did not mix the air with the fuel gases. The burners were connected to the dryers by means of AMCA measuring ducts (Ashrae 1977).

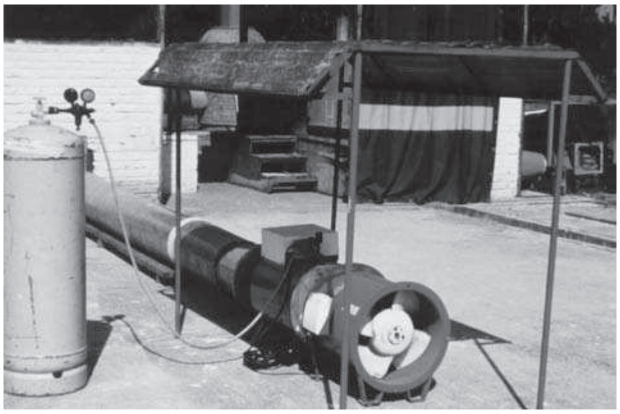

Figure 22-4. A diesel heating system coupled to an artificial fixed-bed dryer.

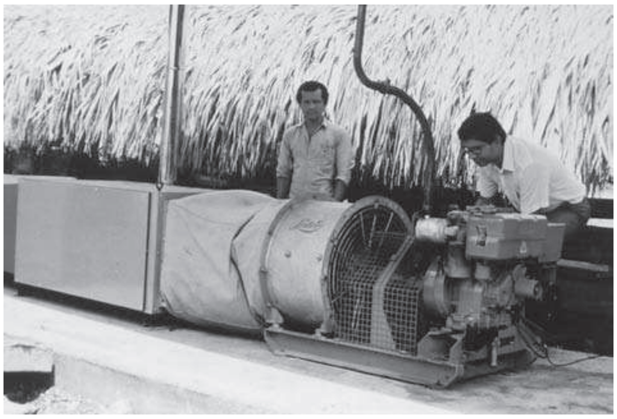

Figure 22-5. A propane gas heating system coupled to an artificial fixed-bed dryer.

Air flow was determined with a blade anemometer, a pitot tube, and an inclined-tube manometer with a scale 0 to 2.4 inches of water and a ±0.02 accuracy. In the dryers' plenum, the air temperature was measured with a mercury thermometer, calibrated from 0 to 120 °C and a ±1 °C accuracy.

Evaluating the artificial drying systems

The solar collector. The solar collector was studied in February and March 1984. Results were classified into two groups: one evaluating the solar collector's performance, and the other the dryer's capacity when the collector was used to heat the air. Results are presented in Table 22-1.

The collector operated daily from 7:00 to 19:00 hours, during which time it heated an air flow of 106 m^3/min at an average temperature of 36 °C. The initial temperature of ambient air averaged 31 °C.

Relative humidity of the air dropped from 62% to 46%. The collector's efficiency was defined as the ratio between the average amount of energy absorbed by the air and the energy of incident solar radiation. The result was 63%, a standard value, according to Rossi and Roa (1980) for this type of collector.

Table 22-2 shows the results obtained when the dryer was coupled to the solar collector. On applying various air flows, different drying times were obtained, which were expressed as net daylight hours between 7:00 and 20:00 hours. Nocturnal hours, during which the process was suspended, were included. The number of batches that could be dried per week, considering drying time, was determined on the basis that new batches were not processed after the one that finished after mid-day.

Table 22-1. Value[a] of parameters by which a flat solar collector with a 30-m^2 absorbent surface[b] operates.

Ambient air		Solar radiation	Air flow	Temperature (°C)		Efficiency
Temp. (°C)	r.h. (%)[c]	(cal/cm^2 per min)	(m^3/min)	Increase	Final	(%)
31	62	0.62	106	5	36	63

a. Average values over 43 days of observations between 7:00 and 19:00 hours.

b. Absorbent surface was constructed with corrugated zinc sheets, painted in matte black and placed under a cover of polyethylene sheeting.

c. r.h. refers to relative humidity.

Table 22-2. Effect of air flow applied over time within an artificial fixed-bed drying system that is coupled to a flat solar collector.[a]

Applied air flow (m^3/min per t)	Drying time		Capacity per week	
	Net[b] (h)	Production[c] (days)	Batches (no.)	Dried chips (kg)
78	41	3.2	1.5	810
88	42	3.3	1.5	720
100	29	2.2	2.0	840
118	26	1.6	3.0	1077
141	20	1.3	3.0	480

a. Average values of three replications by level of applied air flow. General trial conditions were as follows:
  - Moisture content of cassava chips = initial: 64.5% ± 2%; final = 12.3% (interpolated).
  - Air: temperature = 36 ± 2 °C; relative humidity = 43.5% ± 6.5%; flow = 106 m^3/min.
  - Solar radiation (cal/cm^2) = 0.60% ± 10%.

b. Daylight drying period = 7:00 to 20:00 hours.

c. Includes nocturnal hours during which drying was suspended.

This standard was adopted because the product's final quality could not otherwise be guaranteed. The chips deteriorated if their drying was interrupted and their moisture content did not drop below 35% on the first day. If this occurred, the chips appeared yellowish—a general sign of inadequate processing that had left them with a poor appearance. The same thing also happened when drying time continued for more than 2 days.

Although drying can continue after 20:00 hours, this time was not used for reducing moisture content in the chips, because the low temperatures obtained with the collector during those hours did not sufficiently justify expenditure on electric power.

Table 22-2 shows that the largest capacity for drying per week was obtained when an air flow of 118 m^3/min per ton of fresh chips was applied.

Table 22-3 shows the value of investment and production costs of a natural system, compared with those of an artificial system with a solar collector. The artificial system has higher initial costs to pay for the motor-fan unit, and higher production costs to pay for replacing the plastic cover and consuming electric power. As a result, this system does not compete with the natural system, even though this latter system is dependent on environmental conditions.

The use of a solar collector to artificially dry cassava chips, a product whose initial moisture is high (60% to 65%) at relatively low temperatures (34 to 38 °C), requires high air flows. This affects the size of both collector and fan, and limits the system's capacity to 2.5 to 3 t of dried product per batch.

Using three fuels. Table 22-4 gives the results of artificial drying, using three available fuels: coal, propane gas, and diesel. The Table also shows the overall efficiency of the process for different operating conditions and the operating costs generated according to fuel. With the air flows applied and given temperatures, cassava chips can be dried to a moisture content of 12.3% over 5.5 to 10 hours in a normal workday. Fuel consumption was greater for coal than for propane gas. When the temperature or air flow was increased, drying time was reduced but fuel consumption and, therefore costs, were higher.

Propane gas was the most efficient, followed by diesel and coal. Few differences were seen between the latter two fuels. The propane gas's higher efficiency was due to the air being directly heated, as it is mixed with the fuel's gases.

Table 22-3. Costs of investment and production of batch-drying systems with a capacity to produce 2.4 t of dried cassava chips, 1985.

Drying system	Cost of:	
	Investment (US$)[a]	Production (US$/t)
Natural: on concrete floor (500 m^2)	183.6	11.9
Artificial: fixed-bed and solar collector[b]	566.7	12.6
Difference	383.1	0.7[c]

a. US$1.00 = Col$1800 in 2010.

b. Costs of system elements: chamber (30 m^2) = US$111.1; solar collector = US$122.2; motorized fan = US$333.3

c. This difference in production costs is due to the replacement of the plastic cover and consumption of electric power in artificial drying.

Table 22-4. Effect of temperature and air flow on drying time and fuel consumption, and on two parameters (efficiency and costs) of the artificial cassava drying system with three different sources of heat.[a]

Air temp.[b] (°C)	Air flow (m^3/min per t[c])	Net drying time (h)	Fuel consumption[c]			Overall efficiency (%) with:			Cost[d] (US$/t[c])		
			Coal (kg/t)	Propane gas	Diesel (gal/t)	Coal (kg/t)	Propane gas	Diesel	Coal	Propane gas	Diesel
50	130	10.0	250	105	65	38	70	36	1625	3150	7150
	190	7.5	390	110	70	32	72	36	2535	3300	7750
60	130	7.5	300	100		35	65			1950	3000
	190	5.5	350	130		25	54			3575	3900

a. Average of three values per treatment. General trial conditions were as follows:

- Average temperature of ambient air = 26 °C.
- Moisture content of cassava chips (%) initial = 61% ± 2%; final = 12% (interpolated).
- Heat value of fuels (kcal/kg): coal = 6,700; propane gas = 14,000; diesel = 41,000
- Efficiency of burners: coal = 60% ± 5%; propane gas = 95% ± 2%; diesel = 76% ± 2%.
- Fuel prices in 1985: coal = US$0.004 per kg; propane gas = US$0.02 per kg; diesel = US$6.1 per gallon.

b. The diesel heating system, on its own, provides a temperature of 50 °C.

c. t refers to tons of fresh cassava chips.

d. US$1.00 = Col$1800 in 2010.

Although drying with coal was the least efficient and consumed the most fuel, operating costs were the lowest because its price per kilogram was relatively low. Higher air flows and temperatures meant higher operating costs. In this regard, the difference between coal and propane gas diminished. Accordingly, choosing between them has to be based on the availability of fuel and costs of combustion and heating equipment. Table 22-5 presents these costs, together with those of the burners, heat exchangers, fans, and controls that form each unit. The end result tends to favor the coal option, which presents lower costs of both investment and operation.

Economic analysis

Burners form the heat transfer equipment in artificial dryers, with coal having advantages over propane gas or diesel. Hence, an economic study of the four alternatives for investment was carried out, using the conditions of production and marketing of dried cassava chips in the Atlantic Coast, where dried cassava technology is supported. Cost data are expressed in American dollar (US$). The principal assumptions of this analysis are presented below:

Table 22-5. Cost of combustion equipment, using diesel, propane gas, or coal, with a capacity of 70,000 kcals per hour, 1985.

System	Investment cost (US$)[a]
Coal	261.1
Diesel	680.6
Propane gas	358.3

a. US$1.00 = Col$1800 in 2010.

- *Production capacity* is determined according to the capacity of a model plant in the Atlantic Coast, and is calculated as 538 t of dried cassava chips per year.
- *Price of raw material* is US$4.44/t of fresh cassava roots, the value reported by drying plants during the operational year 1985.
- *Conversion factor* of fresh roots to dried chips is 2.5. That is, 2.5 t of fresh cassava roots are needed to produce 1 t of dried cassava chips.
- *Sale price* per ton of cassava chips dried to a moisture content of 12.3% was US$15.11. (This is 85% of the price for sorghum in 1985.)
- *Coal consumption* costs US$0.004/kg per 450 kg/t of fresh cassava chips.
- *Workdays* per week: 6.
- *Drying methods*:
  - Natural, on concrete floors
  - Artificial, fixed-bed, with air heated to 60 °C, using coal.

The prices of fresh roots and dried chips can vary over the project's life. For this analysis, the prices are assumed to be in constant currency, that is, they are deflated by the same index. Table 22-6 describes the four investment alternatives:

- *Alternative 1* corresponds to a model plant in the Atlantic Coast. It operates during summer (December to April) over 20 weeks per year.

Table 22-6. Description of four alternative investment structures for drying cassava chips.

Parameter	Alternative			
	1	2	3	4
Drying method	Natural	Natural	Natural/Artificial	Artificial
Annual operational period (no. of weeks)	20	35	20/30	50
Drying system	On 2000 m^2 of concrete floor	On 1300 m^2 of concrete floor	On 1000 m^2 of concrete floor/ 20-m^2 fixed-bed dryer	20-m^2 fixed-bed dryer
MCP[a] by batch (t)	24	13	12/4	4

a. MCP = maximum capacity for processing fresh cassava chips.

- *Alternative 2* is the same as Alternative 1, but operates for an extra 15 weeks, during the transitions from winter to summer and summer to winter, or in regions where summer is longer, as in the northeastern departments of the Atlantic Coast, where warm spells occur.

- *Alternative 3* operates for 50 weeks of the year, with 20 weeks with a natural drying system on concrete floors, and 30 weeks of rainy season with an artificial, fixed-bed, drying system.

- *Alternative 4* also operates for 50 weeks per year, but uses only an artificial drying system.

Table 22-7 shows the investment needed for equipment (chipping machines, dryers, and motors), tools, and working capital (the money needed to buy raw material for 1 month's operation). It varied from plant to plant, because the period of annual operation was different for each, even though their production capacity was the same. Some plants therefore handled larger monthly volumes of fresh cassava than others. Table 22-8 gives the production costs per ton of dried cassava chips. Processing costs includes labor, maintenance, and consumption of electric power and coal.

With data tabulated, the profitability or rate of return was calculated on a personal computer, equalizing income values to payment values. The four alternatives were economically feasible, with their profitability rates at 26.4%, 37%, 12.6%, and 12.4%, respectively. Alternative 2 was the most profitable because it used its installations over a longer period, and had low operating and investment costs. Alternative 4 required the least investment, but had the highest operating costs.

Table 22-7. Value of investment and working capital for the four alternative investment structures for drying cassava chips, 1985.

Parameter	Alternative			
	1	2	3	4
Initial investment (US$)[a]	1,721	1,269	1,946	1,410
Working capital (US$)[a]	1,196	684	478	478

a. US$1.00 = Col$1800 in 2010.

Table 22-8. Production costs (US$) a per ton of dried cassava chipsb according to four alternative investment structures, 1985.

Parameter	Alternative			
	1	2	3	4
Raw material (fresh cassava roots)	11.1	11.1	11.1	11.1
Processing	2.0	2.0	3.0	3.6
Total	13.1	13.1	14.1	14.7

a. US$1.00 = Col$1800 in 2010.
b. Components: moisture content at 13.7%; protein, 3.5%; fat, 0.5%; fiber, 10%; carbohydrates, 78.6%.

The economic data of the analysis were valid for summer, when dried cassava chips were produced. In winter, dried cassava chip production was nil, given that natural drying was being used. Hence, the price increased, reaching US$20.6 per ton or more, especially when sorghum imports were also restricted and scarce on the market.

If the supply of dried cassava chips could be year round, then the price could be expected to stabilize to a balance between supply and demand, or agreements could be made to stabilize it. Hence, the same price was considered for all alternatives, even though they had functioned in different seasons of the year.

However, the price of collecting fresh cassava roots varies with the changeover from dry to rainy seasons; difficulties in harvesting, collection, and transport; or scarcity. Although obtaining raw materials most affects production costs, the same price was also considered for this factor when analyzing the four alternatives because no information was available for predicting a reliable price during the rainy season. Hence, if a project of dried cassava chip production is to be profitable or to expand its capacity throughout the year, a drying plant must not only be located in a cassava-producing region, but should also develop its infrastructure and grow its own crops. Thus, raw material supplies will be guaranteed and at a stable price.

Conclusions and recommendations

The evaluation of technologies for producing dried cassava chips, by creating an agroindustry in the Colombian Atlantic Coast, led to the introduction of improvements to production. This could not have happened if the work had been at an experimental level. These improvements manifested in reduced production costs and consequent increases in profits for the project.

The production of dried cassava chips and their use as a source of calories to substitute certain grains (especially sorghum) in animal feed has generated a growing demand for this product in the market. To meet this demand, both the production and processing of cassava chips must be developed:

- For *production*, both yield per hectare and area cultivated must be increased. Thus, cassava may be produced for the fresh-root market, which pays higher prices, and for industries using dried cassava chips.

- For *processing*, the use of a natural drying system confines work to dry seasons of the year and thus the processing of the largest volumes of fresh cassava roots to these periods. The product becomes distributed throughout the rest of the year. This increases capital costs as it requires increased capacity and storage.

However, the use of an artificial fixed-bed dryer, with coal as a source of energy, is the best alternative to enable a year-round offer of dried cassava chips. Furthermore, product quality can be improved, an advantage when incentives are paid for quality or the product is marketed for human consumption, thereby achieving better sale prices.

Given the study conditions, the two systems—natural drying (ND) and artificial drying (AD)—are profitable options. ND offers higher profits than AD because of lower investment and operating costs. However, the two operational alternatives can be complemented to increase production capacity.

A solar collector for AD is not feasible because considerable energy is needed to evaporate the large quantity of moisture contained in fresh cassava chips. That energy cannot be provided with the temperatures achieved with this system.

A sensitivity study is recommended to establish the effect of the price of raw material, sale price, conversion factor of fresh to dried cassava chips, and consumption and price of coal on the profitability of a project to produce dried cassava chips that alternatively uses ND or AD.

Technology 2:

Producing Dried Cassava Chips for Human Consumption

Sonia Gallego, Lisímaco Alonso, and José Alberto García

Introduction

For more than four decades, different cassava drying systems have been studied for their efficiency, technical and economical feasibility, and reliability for product quality. However, most of the technologies developed focused on dried cassava chip production for animal feed, overlooking the potential of dried chips as cassava flour for human consumption.

In 2000, when CLAYUCA revisited the theme of producing high-quality cassava flour, evaluations of different artificial cassava drying systems were also started (García et al. 2006). Tools, including mathematical modeling, were used to predict the performance and characteristics of cassava drying under certain operational conditions (Gallego et al. 2003). The objective was to develop a procedure for producing dried cassava chips, using artificial drying methods that would guarantee a permanent offer of the product at competitive prices and a quality that was safe for human consumption.

The quality of dried cassava chips depends largely on the processing technology used. However, obtaining raw material of excellent quality is also very important. Adequate control must be carried out at all stages of the process to guarantee the acquisition of a product that meets the standards of quality established for raw materials used to prepare foodstuffs.

Thus, according to the evaluations made, a processing prototype was developed for producing dried chips of optimal quality on equipment at CLAYUCA's pilot plant in CIAT's facilities, Palmira, Colombia.

Producing dried cassava chips

The operations required for producing dried chips are described in Figure 22-6. Ideally, all equipment or parts thereof that come into direct contact with cassava chips must be constructed or lined with stainless steel sheets to guarantee the prevention of contamination. Otherwise, washing and continuous disinfection of all equipment, tools, and installations used in the process become indispensable.

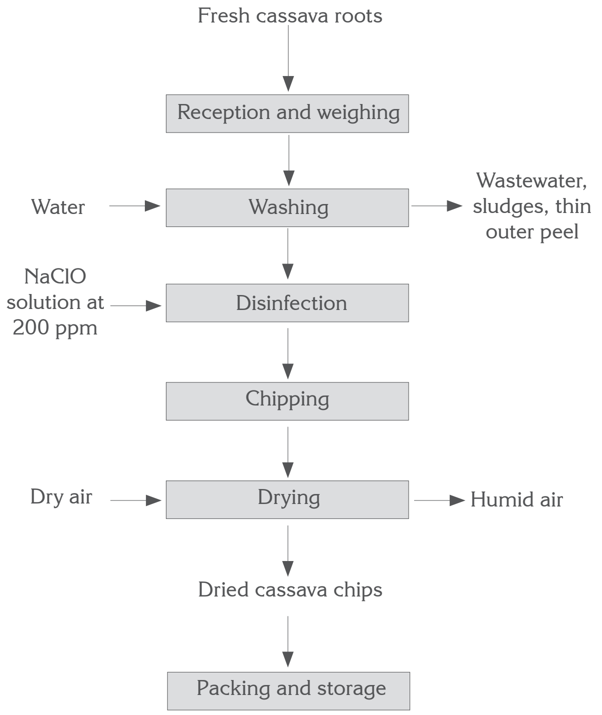

Figure 22-6. Flow chart of dried cassava chips production at the CLAYUCA pilot plant in CIAT.

Reception and weighing. After harvesting, cassava roots are transported, either packed or in bulk, to the drying plant. There, they are unloaded and stored for a maximum of 1 day before processing (Figure 22-7). The cassava is weighed to determine the parameter of yield or the conversion factor of fresh roots to dried chips. The roots should be processed without delay as, within the first 48 h after harvest, symptoms of deterioration develop, principally as color changes in tissues (Figure 22-8).

Figure 22-7. Cassava roots being stored before processing into chips.

Figure 22-8. Typical symptoms of deterioration in cassava roots.

Washing. Harvested cassava roots carry a large quantity of soil and field residues, making their washing before chipping necessary to ensure the dried product's nutritional quality. Washing is carried out in a rotary cylinder, which moves the roots as it washes them with clean pressurized water applied inside the drum. The cylinder walls are perforated to permit the exit of wastewater and residues (mainly the thin outer peel of cassava roots). The equipment also has a loading gate for the length of the cylinder and a feed hopper at one end (Figure 22-9).

About 1 m^3 of potable water is required per ton of fresh cassava roots. For the daily washing of equipment and installations, 2 m^3 are used. Overall, the plant requires 4 m^3 of water per process.

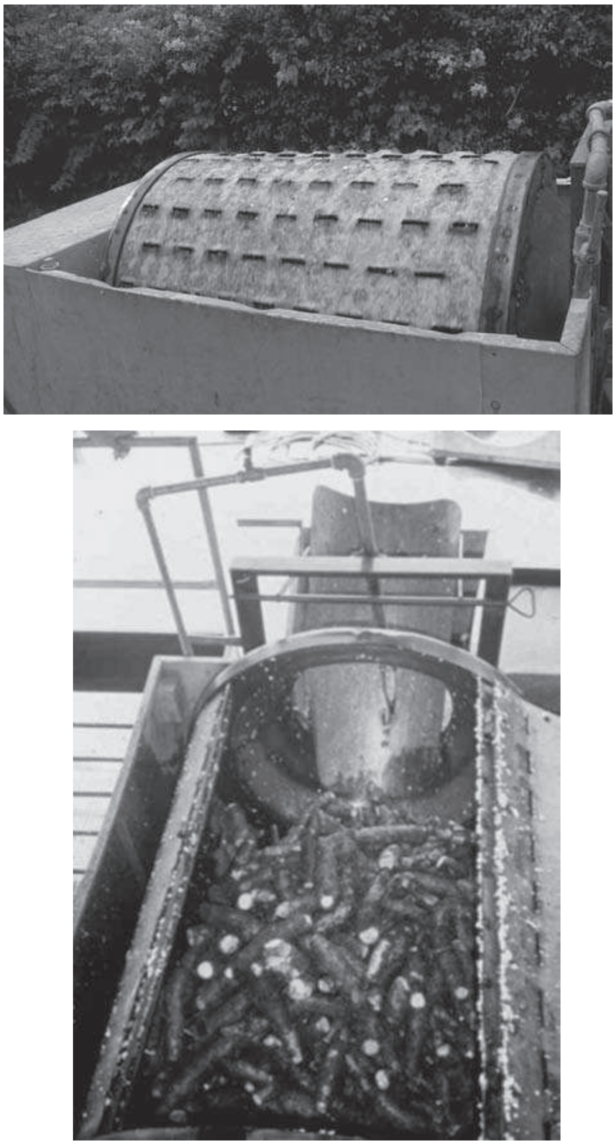

Figure 22-9. Cassava washing machine.

Disinfection. When the roots are clean, they are disinfected, using a diluted solution of sodium hypochlorite (NaClO). This solution is also applied for a few minutes when the roots are in the cylinder.

Chipping. To accelerate the drying rate and thus obtain a good quality product, roots should be cut into small chips of uniform size that increase the surface area exposed to the drying air. Chipping equipment basically consists of a chipping disk assembled vertically onto a structure that supports both the disk's axis and the feed hopper (Figure 22-10). The disk possesses coupled blades that, as the disk spins at 600 rpm, create chips shaped as rectangular bars (Figure 22-11).

Drying. The use of dryers with hot air circulating directly across a fixed bed is the most favorable alternative in terms of quality of end product. Moreover, this method can be used where environmental conditions are not conducive to natural drying.

Artificial drying over a fixed bed consists basically of a uniform flow of hot air passing through a layer, 10 to 30 cm thick, of fresh cassava chips. The dryer is a compartment of simple construction. The product rests on a false floor with perforations, with a fan

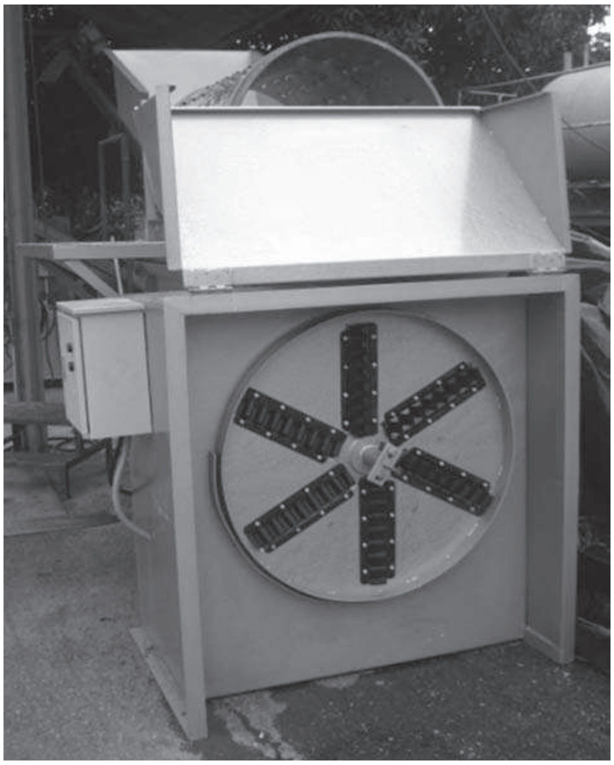

Figure 22-10. Cassava chipping machine.

Figure 22-11. Fresh cassava chips.

forcing the hot air to circulate through the layer of chips. Before it makes contact with the fresh cassava chips, the air is heated in a unit that consists of a burner that is connected to the dryer by ducts. So that drying is uniform, the product must be continually mixed or turned. Although mixing can be manual (Figure 22-12), mechanical mixers are preferable.

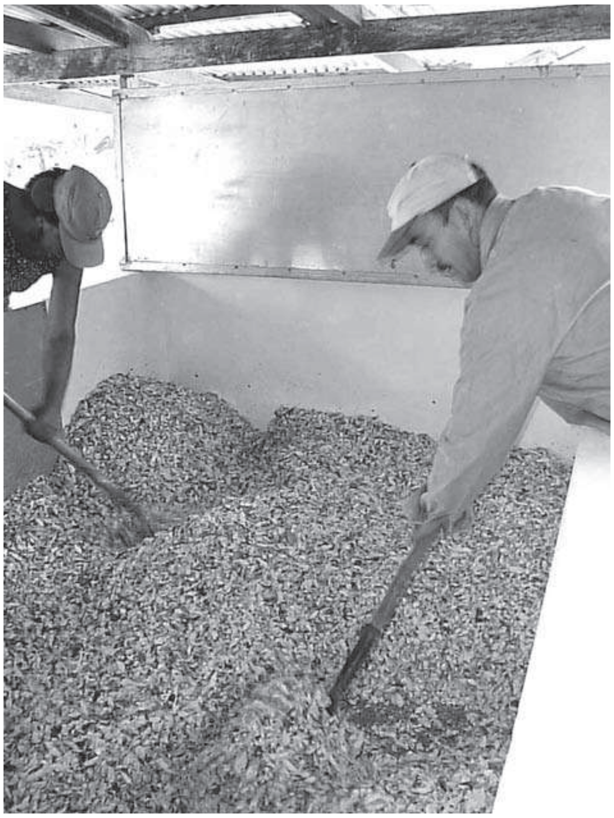

Figure 22-12. Manually mixing cassava chips in the artificial fixed-bed dryer.

For these dryers, the exposed area of the product, temperature, and air flow and humidity must be taken into account, as these variables affect drying times and fuel consumption, themselves significant parameters for determining the process's overall efficiency and operating costs.

Packing and storing. Once the chips have reached a suitable moisture content (10%–12%), they are packed in polypropylene sacks (Figure 22-13). The plant should have a room built for storing dried chips. When storage conditions are adequately controlled, dried cassava chips may be conserved for 6 to 18 months without quality deteriorating. Optimal conditions are achieved if the storage site is kept clean, in good sanitary condition, and free of insect pests.

Evaluating the artificial drying system

Drying is the most important operation in the production of dried chips because of time and fuel requirements, especially as cassava has a high initial moisture content. To evaluate the technical and economic feasibility of the fixed-bed dryer for producing dried chips for human consumption, different trials were carried out to determine the values of the main variables intervening in the process (García et al. 2006).

The equipment used for the evaluation was a fixed-bed dryer with forced circulation of hot air, belonging to CLAYUCA and located at CIAT's facilities in Palmira (Figure 22-14). For the trials, the operation of the equipment and burner was adjusted. Drying curves were established for different loads and operating conditions were determined to obtain a good quality dried product.

Figure 22-13. Dried cassava chips packed in polypropylene sacks.

Figure 22-14. CLAYUCA's artificial fixed-bed dryer at CIAT, Palmira.

Loads ranging between 600 and 1200 kg of fresh chips were managed in one or two 6-m^2 drying chambers. Air flows were heated between 60 and 70 °C, and applied at 115 to 230 m^3/min per ton of fresh cassava chips. The chips' initial moisture content ranged between 58% and 70%.

Table 22-9 shows the average results of the trials carried out with the artificial fixed-bed dryer. According to the initial chip load, various air flows were used and different drying times were obtained for each. Overall, for the different flows applied, drying times ranged from 8 to 18 h.

When air flow was reduced, drying time increased, but fuel consumption (in this case, diesel) was less in terms of quantity of dried chips. Table 22-9 also presents the calculated consumption of natural gas and coal for different air flows, to compare with less expensive fuels in the calculation of the production costs of dried chips. Figure 22-15 illustrates a typical curve for the fixed-bed dryer, for which drying time was about 8 h to reach a moisture content of 12% in the chips.

Table 22-9. Drying times and average fuel consumption for trials carried out with a fixed-bed dryer.[a]

Air flow (m^3/min per ton fresh chips)	Net drying time (h)	Fel consumption		
		Diesel (gal/t dried chips)	Natural gas (m^3/t dried chips)	Coal (kg/t dried chips)
230	8	90	353	602
180	11	88	345	589
150	13	86	340	580
120	18	80	313	535

a. Average ambient temperature = 25 °C.
Average air drying temperature = 65 °C.
Average initial moisture content of chips = 65%.
Average final moisture content of chips = 12%.

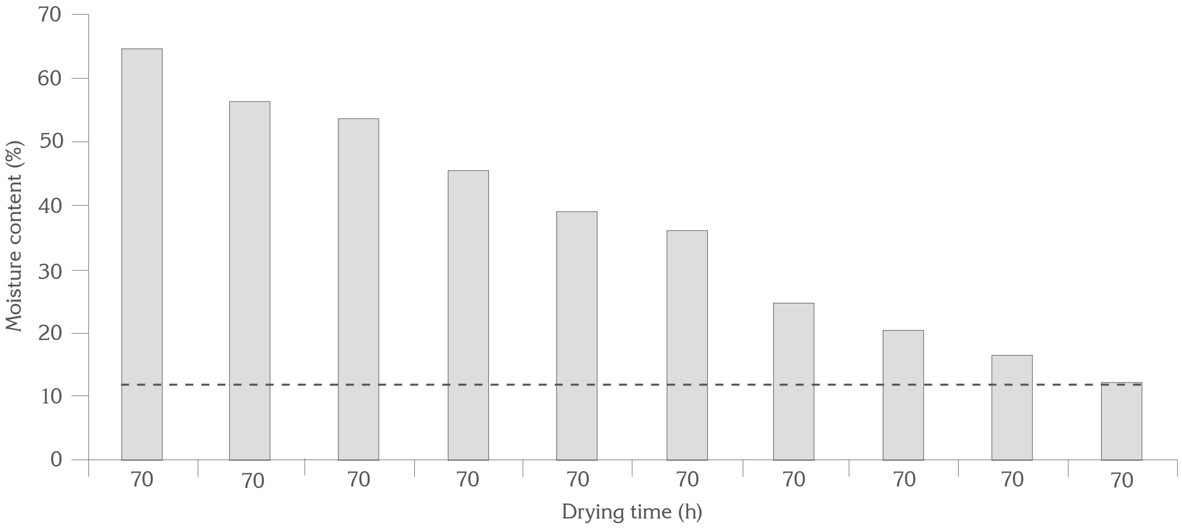

Figure 22-15. Typical curve presented when cassava chips are dried, using an artificial fixed-bed dryer.

The data in Table 22-9 were used to estimate the production costs of dried cassava chips obtained through artificial fixed-bed drying, using natural gas as fuel and an air flow of 120 m^3/min per ton of fresh cassava chips. Table 22-10 shows that the total production costs of 1 t of dried cassava chips, using a fixed-bed dryer with natural gas as fuel, would be US$361.1. However, if coal was used instead as fuel, the cost would be US$299.1, a drop of almost 20%.

In conclusion, if more economical fuels are used for drying, the best quality dried cassava chips can be obtained at low production costs.

Quality of dried cassava chips for human consumption

A product's quality is measured by the way in which its characteristics comply, among other aspects, with:

- Legal health provisions
- Composition
- Taste or acceptability to consumers

A product may comply with legal provisions but nevertheless be rejected by consumers for such attributes as color, flavor, aroma, and chemical composition. Hence, quality control should involve not only compliance with legal provisions but also aspects that determine acceptance by consumers.

With respect to the dried chips' final quality, not only should the raw material be of good quality, but supervision and control should also be carried out at all stages of processing. The difficulty of carrying out such activities in practice means that the finished product, that is, the dried cassava chips, must be continuously and systematically reviewed.

In short, dried cassava chips should comply with given requirements imposed by the market. These characteristics include chemical composition, sanitary condition, physical characteristics (size, rheology, color, and viscosity), and sensory characteristics (aroma and flavor).

Chemical composition. The usual chemical composition of dried cassava chips is presented in Table 22-11. Although composition values are usually constant, ranges are reported, as these values depend largely on factors such as variety, sanitary quality, type of processing, and moisture content of the dried chips (Alonso and Zapata 2005).

Table 22-10. Total production costs of dried cassava chips, using an artificial fixed-bed dryer, Colombia, June 2010.

I. Basic information				
Conversion factor for fresh to dried cassava chips = 2.6:1				
II. Variable costs per ton dried chips	Unit	No. units/t dried chips	Unit value (US$)[a]	Cost/t (US$)[a]
Inputs				
Raw material[b]	t	2.6	55.55	144.4
Fuel (natural gas)	gal	313.0	0.39	122.1
Energy for process	kWh	218.0	0.11	24.0
Washing water	m^3	2.5	0.49	1.2
Sacks	unit	25.0	0.37	9.2
Labor[c]	workday	2.0	13.89	27.8
Total variable costs				328.7
III. Fixed costs/ton dried chips				Cost/t (US$)
Depreciation and maintenance[d]				32.4
Total fixed costs				32.4
Total production costs/ton dried chips[e] (US$)				361.1

a. US$1.00 = Col$1800 in 2010.
b. Price of fresh cassava roots as delivered to plant.
c. Assuming a workday of 8 h.
d. Depreciation over 10 years; maintenance at 4% annually; initial investment at US$27,778.
e. Production costs obtained for the conditions and equipment at CLAYUCA (fixed-bed dryer).

Table 22-11. Average values for chemical constituents of dried cassava chips destined for human consumption.

Parameter	Range
Moisture content (% wb)[a]	10–13
Starch (%)	60–85
Protein (%)	1–3
Crude fiber (%)	1–4
Ether extract (%)	1–2
Ashes (%)	1–3
Total sugars (%)	2–5
Total cyanide (ppm)	10–30

a. wb refers to wet basis.

Overall, dried cassava chips are characterized by their low contents of protein, fiber, and ether extract (fat), but high levels of carbohydrates, which comprise mainly of starch and small amounts of sugars. The peel or cortex represents 15% to 20% of the cassava root's total weight, with the pulp or parenchyma amounting to 80%–85% (Alonso and Zapata 2005).

To produce refined flour, dried cassava chips are ground and sieved, removing most of the peel, thin outer peel, and fiber as a solid waste byproduct. Most of the protein, fat, fiber, and ashes are located in the cortex, the principal component of the solid waste, whereas the carbohydrates are located in the parenchyma, the principal component of refined flour.

The standard used for quality in Colombia for dried cassava chips destined for human consumption is the Colombian Technical Standard NTC 2716, issued by the Colombian Institute of Technical Standards and Certification (ICONTEC, its Spanish acronym). At world level, the quality standard is the CODEX STAN 176-1989 for "edible cassava flour", developed by the Codex Alimentarius Commission for cassava flour obtained from dried cassava chips.

Microbiological quality. Apart from the average characteristics of size, presentation, and chemical composition, dried cassava chips for human consumption must also meet the microbiological requirements called for by the Ministry of Health in each nation. Table 22-12 shows the maximum values permitted by the Colombian Government, according to Standard NTC 2716. In short, the product must be free of microorganisms and parasites, and must not contain any substance derived from microorganisms in quantities that may endanger health.

Table 22-12. Microbiological requirements for dried cassava chips destined for human consumption.

Analysis	Maximum limit
Total count of aerobic mesophiles (cfu/g)	200,000
Count of total coliforms (cfu/g)	150
Count of *Escherichia coli* (cfu/g)	3
Count of *Staphylococcus aureus* (cfu/g)	100
Count of fungi and yeasts (cfu/g)	2,000
Detection of *Salmonella* spp. in 25 g	Absent
Count of *Bacillus cereus* (cfu/g)	1,000

Uses of dried cassava chips

The production of dried cassava chips to obtain refined flour destined for human consumption is of great importance at national and international levels, as they may constitute a raw material of special interest for numerous food-processing industries.

Dried cassava chips used to produce high-quality refined flour may partially substitute not only wheat flours, but also flours of other grains such as maize and rice, in food formulations, including for breads, pastas, pie mixtures, confectionery, flour mixtures for beverages and soups, extruded products or snacks, and processed meats (Ospina et al. 2009).

Even with partial substitution of other flours with cassava flour, food-processing companies can save costs as, in most cases, cassava flour can be obtained at lower prices than the other flours.

Finally, so that an agroindustry of this type is sustainable over time, the following aspects should be considered: a guaranteed supply of quality cassava roots at adequate volumes and stable prices; an efficient, economic, and reliable technology in terms of the end product's quality; and support from food-processing industries that identify cassava flour as a suitable raw material that will, on the one hand, bring economic benefits to their business and, on the other hand, contribute to the cassava crop's agroindustrial development and promotion in their region.

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