**CHAPTER 26**

**Sour Cassava Starch in Colombia***

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**Introduction**

Sour cassava starch is a fermented product used in the food industry. It was initially produced by rural families for domestic use, and they employed homemade, manual tools for its extraction. It has been used as an ingredient in different foods, especially those of regional or traditional origin where the breadmaking potential of cassava starch is needed.

As an agroindustrial activity in Colombia, cassava starch extraction began in the 1950's. The demand for the starch increased over the following years, and its extraction became a completely handmade agro-industry. From then on, mechanical innovations for certain processing steps were introduced, thereby boosting the production capacity of these small factories that began to call themselves “rallanderías” or “ralladeros”; in this text, they will be referred to as cassava starch extraction plants or simply extraction plants. This activity had a positive impact on the socio-economic level of poor smallholders living in the northern zone of the Colombian department of Cauca (CECORA 1988; Gottret et al. 1997a; Gottret and Ospina 2004).

More than 200 of these extraction plants involved in producing cassava starch for bakery goods (such as pandebono, pandeyuca, etc.) have been set up in Colombia, and they are harnessing that product’s special breadmaking properties.

Sour cassava processing principles are applied across all extraction plants, although the technology used varies significantly. For example, some of them process everything completely by hand, others have implemented mechanization yet they are still very traditional, and then there are those with very high technological processes but remain at a small-scale industrial level (Zakhia et al. 1996).

Furthermore, there are plants that are large-scale producers of native or natural (unfermented) cassava starch in the departments of Atlántico and Sucre (Alarcón 1993a, 1993b); this process uses a higher degree of technology. Native starch (also known as sweet cassava starch) is used in different industrial sectors (mainly glue and paper manufacturing), the textile industry (warp sizing), and prepared food industry as well as in oil well drilling and dynamite manufacturing.

In 1989, the French Agricultural Research Centre for International Development (CIRAD)* and the Centro Internacional de Agricultura Tropical (CIAT) launched the Cassava Development Project in Latin America, which aimed to improve traditional technology used in small-scale cassava starch processing by developing technologies that would increase starch extraction profitability and product quality and could be transferred to rural producers (Chuzel and Muchnik, 1993; Alarcon, 1996).

Most of the project activities, including an important survey of producers in 1995, were undertaken in the department of Cauca, where cassava starch extraction plants are found on both sides of the Pan-American Highway along the section between

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3. For an explanation of this and other acronyms and abbreviations, see Appendix 1: Acronyms, Abbreviations, and Technical Terminology, this volume.
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Pasto-Popayán-Cali. These plants are basically dedicated to producing sour cassava starch. Only a few produce natural starch.

This collaborative project aimed to technologically improve cassava processing for obtaining the natural and sour starch from this root. Its results can be applied to most of the Latin American, Asian, and African cassava-growing regions that have an adequate water supply. CIAT and CIRAD objective is to spread these technological innovations among tropical smallholder farmers, whereby they can take advantage of an agricultural product that so far has served them only as a means of subsistence in order to improve their socio-economic level.

Since 1991, these two institutions have transferred sour cassava extraction technology (herein described) to different Colombian regions. In 1993 and 1994, this transfer work was continued in Ecuador. In 1997 and 1998 introduced the technology for improved sour starch processing to some cassava-producing regions of Nicaragua, and it is currently conducting a feasibility study for transferring it to other Latin American countries and other continents.

Cassava cultivation

Cassava (Manihot esculenta Crantz) is a starchy root crop grown in the tropics and subtropics. Although it is one of the most important food crops in tropical countries, it is not well known elsewhere.

It originated in tropical America. Even before the turn of the 17th century, Portuguese explorers were taking it with them to Africa and Asia. It is now cultivated in 92 countries, where it feeds more than 500 million people.

Plant and cultivation

At the present, there are more than 6500 cassava varieties, each one with its own peculiar characteristics.

Its flowers (male and female) are small and cross-pollination is a frequent occurrence. Its fruits are dehiscent, and seeds are small and oval-shaped. The root is conical, with an external and an internal bark (white or pink in color). The mature stalks are cut into 7–30 cm stakes or cuttings, which are subsequently used for propagation purposes.

Under experimental conditions and in a monocrop system, cassava yields up to 90 t of roots/ha (25–30 t dry matter/ha); however, average global yield in actual conditions (marginal soil, severe climate, and association with other crops) is 9.8 t/ha (12.4 t/ha in Latin America). One ton (1000 kg) of fresh cassava yields 280 kg of flour, 230 kg of starch, 350 kg of dry chunks, or 170 L of alcohol (CIAT 1996).

While cassava is a hardy plant, it is susceptible to three significant diseases: bacterial blight (on leaves and stems), root rot, and the African mosaic virus (just in Africa). Several sap-sucking insects (green aphid, mealybug, whitefly) and some phytophagous pests (hornworms) attack the leaves. The roots are sometimes damaged by burrower bugs.

Cassava can withstand drought (without affecting production) because it possesses three particular characteristics: (1) stomata close when air is dry, (2) roots extract water from deep soils (up to 2.5 m), and (3) its photosynthesis system captures atmospheric carbon even when it has limited water (under prolonged hydric stress).

This crop survives in low-phosphorus soil because it creates associations with fungi (mycorrhizae) that provide this element. It also grows in acid soils (with aluminum). Cassava does not tolerate waterlogging. Roots can be harvested 7 months after planting and can remain in the ground for up to 3 years. Once they are harvested, they deteriorate within 3 to 4 days. As a result, they must be consumed or processed without delay.

Cassava should not be simply regarded as a crop for human consumption since a considerable amount of production is processed and sold as starch and other derived products. Although the virtues of this crop are beginning to spread out, it is often feared that its expansion can damage soil fertility and cause erosion, particularly those seen as marginal agricultural lands.

In fact, cassava extracts an amount of nutrients that is similar to the level extracted by other plants. Moreover, under proper agronomic management, its production is sustainable. Furthermore, cassava has the ability to grow in depleted soils, an extraordinary advantage that, when coupled with its huge production potential, presages this crop will have an important future as a basic energy source for marginal regions of the tropics (Cock 1989).

Despite it prefers hot and humid climates, cassava adapts to a large range of climatic conditions. It grows very well between latitudes 30° N and 30° S.
Root analysis

Cassava roots (Figure 26-1) are composed of three tissues: periderm (bark), cortical parenchyma (peel), and parenchyma (Figure 26-2).

- Approximately 80% of the fresh root weight comes from the parenchyma or pulp, the tissue in which the plant stores the starch.
- Root dry matter content fluctuates between 30% and 40%.
- Parenchyma dry matter is primarily (90%–95%) composed of the non-nitrogenous portion, i.e. by carbohydrates (starches and sugars).
- The remainder of the dry matter is fiber (1%–2%), fats (0.5%–1.0%), ash or minerals (1.5%–2.5%), and protein (2.0%).
- Starch represents the largest portion of the carbohydrates (96%) and is, hence, the main component of the root dry matter.

Cultivated varieties with industrial uses should have high starch content (Wheatley 1991; Sánchez et al. 2009).

**Cyanogenic compounds.** Cassava contains a cyanogenic glycoside called linamarin that hydrolyzes and releases doses of cyanhydric acid (HCN) that range from innocuous to toxic and lethal when in the presence of enzymes (mainly linamarase) in an acid environment. This reaction normally occurs in decomposed plant tissues or in animal digestive tracts.

While botany and agronomy previously classified cassava varieties as “sweet” and “bitter” in relation to the amount of HCN they could generate, this classification is no longer used because there is no stability in the “content” of acid or its originator, linamarin, in either category. “Sweet” varieties generally produce below than 60 mg of acid per kilogram of fresh root (a rather small amount), while the “bitter” can generate more than 1000 mg/kg. To date, science has not discovered a non-cyanogenic variety. Environmental conditions may affect cassava’s “content” of cyanogenic compounds such that a “sweet” cultivar grown in one region may become “bitter” in another region.

The root bark contains higher concentrations of cyanogenic compounds, and these are likewise found in leaves and other plant organs, although in lesser quantities. Conventional cooking methods are effective in reducing cyanogenic contents of cassava to harmless levels. However, when roots from a “bitter” variety are consumed, without proper previous cooking and when diets lack protein and iodine (conditions that are generated during war and famine), then people may suffer from cyanide poisoning, a situation that would seriously affect their health.

Processing the roots of a “bitter” variety is quite demanding. However, there are two reasons why some farmers prefer to plant them: (1) the cyanogenic compounds seemingly help to protect the plants from pests (current and potential) and (2) food products made with their starch have better texture.

When high cyanogenic content cassava varieties are processed, the final product (starch) does not contain any residual acid whatsoever, and the reason for that is HCN dissolves completely in the large volume of water required for processing and is thus removed from the starch.
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Varieties

Each cassava variety behaves differently, and the optimal harvesting time is different for all of them. While these characteristics depend upon two conditions inherent to the place where they are grown, namely climate and altitude, they also depend upon the variety’s genetic traits and management practices (Alarcón 1994a).

When cassava’s optimal harvesting period is over, the water and fiber content increase, and the percentage of starch notably decreases. Therefore, in the process of obtaining the starch, a large amount of black starch called “mancha” in Colombia (scum skimmed off the surface of sedimented starch), a byproduct that contains poor quality starch, is produced.

- Pest- and disease-resistant cassava varieties that can adapt to different climatic and soil conditions have been developed. These are high-yield varieties that contain elevated concentrations of starch; many of them reach the harvesting stage in a short growing period (Domínguez [1983]).

- When inadequate growing practices are used, the variety’s yield declines, diseases that attack the plant occur, and the soil loses its minerals and nutrients (Domínguez [1983]).

Production and yield

In the world. Cassava cultivation has been a major traditional activity for rural communities across many countries. It is one of the main components of the food diet of people living in developing nations, who also use it as animal feed, and when there is a surplus, it is sold in the market.

Global cassava production in 1999 yielded more than 169 million metric tons, of which 54.4% (92.5 million) was grown in Africa, 27.6% (47 million) in Asia, and the remaining 18% (29.3%) in Latin America and the Caribbean.

The main cassava-producing nations are Nigeria, Brazil, Zaire, Thailand, and Indonesia. Figure 26-3 shows fresh root production figures (FAO 1999). Annual per capita and per region consumption is higher in Africa (more than 90 kg), and Zaire is the country with the highest level of cassava consumption: 391 kg/person per year, or the equivalent of 1123 calories a day. Global consumption is around 18 kg/person per year.

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Close to 85% of global production (Figure 26-4) is used in the place where it is grown (in situ), and from that percentage, 60% is set aside for human consumption, nearly 33% for animal feed, and 7% for starch production and biotransformation (Jones, 1983).

The remaining 15% (around 30 million tons) is exported each year to Europe and Japan as pellets or starch, and 75% of the product is exported from Thailand, with the rest from Indonesia and China. The European Union annually uses 5 million tons of pellets to supplement animal fodder.

In Colombia. Cassava production in Colombia increased in 1999 to 2 million metric tons, making it
the 16th largest producer in the world (FAO 1999). Average yield is 9.93 t/ha. The primary producing region is the Atlantic Coast, yet a sizeable amount of this product is grown in the Eastern Plains (Llanos Orientales). The department of Cauca accounts for 4.6% of the total national production.

On account of the seasonal rains, most of the annual production takes place during certain times of the year. For the cassava agro-industry, this situation creates a raw material shortage in some months of the year and a surplus in others as well as the loss of fresh roots due to damage from extended storage, when the offer is high, and price fluctuations in raw material and starch.

In the department of Cauca. The department of Cauca (IGAC 1993) is the main producing region of sour cassava starch in Colombia since it processes nearly 80% of the entire national supply. In 1994, there were some 6450 ha of cassava fields in this department from which roughly 53,500 t of fresh roots were produced. This production accounted for 3.2% of the national total.

The average yield in this department, according to Ministry of Agriculture and Rural Development (MADR) of Colombia figures, is 8.3 t/ha. Local production is insufficient to meet the current demand by cassava starch extraction plants. When the department of Cauca experiences a shortage of cassava, it needs to be purchased from other regions of the country.

In order to fully use the installed capacity of the extraction plants, it is estimated that an area of 19,700 ha would have to be cultivated.

The CIAT Cassava Program tested, with good results, some varieties that had been improved in CIAT for Cauca conditions and requirements, in other words, for a determined time between planting and harvesting, high yield, and very high quality starch for breadmaking. Improved and tested varieties still recommended to farmers are the following:

• Catumare variety (CM 523-7). It is a good starch producer and is destined for fresh consumption and for the frozen food industry.

• MBRA 12 variety. It is a high-yield product, a good percentage of starch can be extracted from it, it produces high-quality starch for breadmaking, and it is not stolen from the fields since it is a bitter cassava.

Producers and processors. It is estimated that 97% of producers in Cauca use traditional farming practices for cassava cultivation, only 3% employ more technical methods, i.e., healthy cuttings are planted from improved varieties and farmers use a “package” of efficient agronomic practices, such as the ones recommended by the National Agricultural Research Program.

A 1995 survey found that there were 210 cassava starch extraction plants in the department of Cauca, and 51% of them were also cassava producers. Yet, the area that they cultivated represented just 8% of the department’s entire cassava cultivation area (Gottret et al. 1997a).

Production and benefit. 3.6% of all departmental production is for direct human consumption or animal feed on farms. From the remaining 96.4%, which is the marketable share, agro-industry uses 90% to produce fermented (sour) starch and 10% is sold for direct human consumption in the department (Chacón and Mosquera 1992).

The entire regional agro-industrial sour starch production is estimated to be 10,700 t/year, a figure that represents 70%–80% of the country’s entire production (Gottret 1996). Another 135 t/year of native starch is also produced for industrial use (Gottret et al. 1997b; Henry and Gottret 1998).

Cassava farming- and transformation-related activities in the northern sector of the department of Cauca occupy a major place in the regional economy. They are also the main source of income for almost 4000 rural families that manage the above-mentioned 210 sour cassava starch extraction plants.

Farmers located in areas near the plants supply them with cassava. During periods of raw material shortage, processors organize themselves and purchase cassava from Ecuador and the Colombian departments of Antioquia (the Urabá zone) and Quindío (Armenia). Roots, stored in trucks for the two or more days it takes to transport them, deteriorate and lose their quality.

Cassava Processing

After cellulose, starch is the most abundant carbohydrate in nature. It is one of the main energy reserves in plants and is found in sources as varied as cereals (corn, wheat, barley, and rice), potatoes, cassava (Figure 26-5), and many other crops.
Starch is the most important carbohydrate for human activity due to its role in nutrition and its multi-purpose character in industry and commerce.

As opposed to cereal starch, which requires very high-technology industrial processes to obtain, extracting starch from roots and tubers (potato, sweet potato, achira, and cassava) is very easy in rural settings since all that is needed is grating, sieving, separation with water, sedimentation, and drying.

The overall extraction process for cassava starch is illustrated in Figure 26-6. The washing, grating, and sieving operations have been mechanized, although processors in some regions still do those operations manually.

The extraction plants treat 1–10 t of cassava a day. The technology they used, described later on in this chapter, does not vary much from factory to factory and remains quite traditional. Some of these in the Colombian Andean region have been constructed according to the site topography (Figure 26-7) to harness energy derived from the gravity gradient.

**Root washing**

The purpose of this operation is to wash away the dirt and debris stuck to the cassava root bark and to remove the bark itself (external bark or periderm).

**Washing methods.**

*Manual washing/peeling.* This is done by hand, yet it is also done with the feet in some areas of the departments of Cauca (23 extraction factories) and Caldas (Figure 26-8). The bark detaches itself from the friction caused from one root rubbing against another during the washing. This operation uses a large number of rural family members and therefore is a source of income for communities.

*Peeling.* Roots are peeled manually (with knives) in these extraction plants. This means that the peel (cortical parenchyma) is cut away, leaving the pulp cleaned and bare.

*Mechanical washing/peeling.* Mechanical washing and peeling are done in a cylindrical drum. Cassava roots are washed as they rub against each other and the drum wall.

The wall is slatted (rectangular) so the waste products inside the drum are released through them. The water flow helps clean away the debris (dirt and the remains of the peels) and strip off the root peel.

**Types of washers.**

*Side loading half-shaft cylindrical washer/peeler (Model 1).* The drum is supported by a half-shaft coupled to a bearing housing on one of its ends. The half-shaft propels the drum. This system is installed on a tank where the water and debris are captured.

The drum (Figure 26-9) is made of a single sheet of galvanized steel and covered completely with oval-shaped openings through which water and debris are discharged.
Figure 26-7. Schematic distribution of starch production operations in a cassava starch extraction plant that is designed for sloped terrain to harness gravity.

Figure 26-8. The roots are peeled by the feet during the washing operation in some cassava starch extraction plants. Friction causes the bark to come off.

Characteristics:
- Capacity: 1000 kg of roots per hour
- Water: 100 L/100 kg of roots
- Rotational speed: 30 rpm

Figure 26-9. Side loading half-shaft cylindrical (drum) cassava root washer/peeler.
This washer is loaded and unloaded through a semi-circular opening in the center of one of the drum sides (or bases). There is a hopper (or similar apparatus) on that side for loading and unloading, which is very practically and easily done by hand and does not require the machine to be turned. Therefore, washing/peeling with this machine is quick and practically continuous.

A perforated pipe for supplying the water enters through the same side opening. The roots exit the washer/peeler and drop into a container underneath the hopper.

Front loading center shaft cylindrical washer/peeler (Model 2). This has a single drum driven by a center shaft that is supported on each end by a bearing housing (Figure 26-10a).

Drum walls are made of galvanized steel and contain oval- or rectangular-shaped openings. There is a hatch that runs along the length of the drum for loading and unloading purposes. A perforated pipe, fixed above and running parallel to the drum, sprays pressured water onto it.

These washers/peelers are difficult to load and unload as well as to start. It takes a considerable amount of time to wash and peel the different loads.

Semi-continuous cylindrical washer/peeler (Model 3). This has a single drum driven by a center shaft that spins on bearing housings.

Drum walls are made of galvanized steel and contain oval- or rectangular-shaped openings through which the water and debris are discharged. A hopper is attached to one end for loading the roots into the drum and an exit hatch is coupled to the other end.

To supply the water, a tube runs the entire length of the drum and enters it through special openings at either end in a suitable position so as not to hinder the drum's spinning (Figure 26-10b). In some of these models, the water is sprayed into the drum through a perforated center shaft.

**Washer/peeler capacity.** Washer/peeler capacity depends on the type, whether a traditional (model 1 and 2) or semi-continuous (model 3).

- Traditional models have a capacity of 1000 kg/hr. Water consumption is less than 100 L for every 100 kg of roots. Each load takes approximately 10 minutes to complete.

- The recently developed semi-continuous model 3 has greater capacity (1500 kg/hr) and reasonable water consumption (130 L/100 kg of roots). It is practical and easy to use. Each load takes approximately 5 minutes to complete. These can be attached to grating operations to provide more continuity and therefore streamline the process (CIAT 1995b).

**Washing/peeling losses.** Losses during the cassava root washing and peeling operation depend upon three factors: (1) the cassava variety, (2) the condition of the roots, and (3) the characteristics of the washer.

- Loss of raw material and, hence, of starch from the washer is mainly due to the length of the
washing process and the design of the drum holes. If these have a very large inner rim, they might tear the root tissue and thus shred it into tiny chips. Normal losses per washing load vary between 2% and 3% of the fresh root weight.

- Front loading center shaft-driving washers also lose water because a portion of it splashes out of the drum.

### Grating the roots

Grating refers to the action of releasing the root starch through any method possible. The method's efficiency is called the grating effect (GE) and has been computed (Alarcón 1989) from this equation:

\[
GE = \left(1 - \frac{A_A \times F_R}{A_R \times F_A}\right) \times 100
\]

where:

- \(A_A\) = starch recovered in the fiber residue (%)
- \(F_R\) = raw fiber in the fresh roots (%)
- \(A_R\) = starch in the fresh roots (%)
- \(F_A\) = raw fiber in the fiber residue (%)

As the grating is performed, starch granules contained in the cells of the root are released (Figure 26-5). The efficiency of this operation determines in large part the total starch yield in the extraction process.

The grater. This is comprised of a wooden drum mounted on a steel shaft. The drum is covered on the outside with a sheet of galvanized steel that has been manually punctured along its entirety with a nail (or punch). Generally, there is one to two holes per each square centimeter.

The drum rotates between 1200 and 1300 rpm. The machine yields on average 1500 kg of roots every hour. When water is used, it consumes 90 L/100 kg of roots.

The grating operation. The rough, cutting surface of the drum, produced by the sharp edges of the numerous holes, establishes a cutting line (a rasp) with the inner side of a wooden plank that is placed in front of the drum. This grater produces a pile of grated cassava, the size of the individual pieces being fine or thick depending upon the space (“light”) between the drum and the wooden plank (Figure 26-11).

Grating is usually done with dry roots. Only in special cases is it performed with water, for example, when the machinery can be installed on sloped terrain, thereby taking advantage of gravity so that the water used can easily flow to the next operation or to the waste water tank (where it is treated).

The percentage of starch extraction depends on the grater. If it does not sufficiently shred the root tissue to separate the starch granules from the fiber, then yield from the extraction process will be low, and plenty of starch in the fiber residue will be lost.

The grater cannot be too fine because very small starch granules would be damaged physically and afterward degrade enzymatically. Under these conditions, sedimentation would be slower (fine granules lose density), and greater quantities of black starch would form (CIAT 1995a; 1995b).

Appendix 1 (Photo 26A-2) shows a traditional grater used in cassava starch-extraction plants in the department of Cauca. The grating effect currently reached in this department is close to 80%, which means it is very efficient.

### Sieving

This operation can be done manually, with continuous mechanical sieves or with mechanical sieves that handle individual loads.

**Manual method.** There are 23 small cassava starch extraction plants in Cauca, in the northern section of Valle, and in Caldas that manually sieve grated cassava.

This is carried out using a piece of fabric attached to a wooden frame. The frame is then placed overtop a container or tank where the starch milk from the grated cassava that has been sieved is sedimented out (Figure 26-12).

Yield from the manual sieving process is equal to that of the mechanical sieves used in the Cauca department extraction plants. In fact, it depends upon the cassava variety, type of grater used, and the number of people, and their skill level, involved in the operation (CIAT 1995b).

**Continuous mechanical method.** In the department of Caldas, they use a wooden type of continuous sieve, with a worm gear, the lower part of which is supported by a piece of fabric equal in length to the gear (see Appendix 1, Photo 26A-3). The sieve is

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Located below the grater to help with the flow of the grated cassava mass.

The worm screw, 3.5–5 m long, extracts the starch very easily and facilitates fiber residue expulsion and compression, hence speeding up the time it takes to dry this byproduct at a later date.

Capacity of a sieve of this type is between 200 and 250 kg of cassava per hour. They are currently being used in Riosucio, department of Caldas.

Intermittent mechanical method. This mechanical sieve is made up of a drum connected to a half-shaft that is supported by a bearing housing. It rotates at 20 to 22 rpm and is loaded and unloaded at one end through a hopper (Figure 26-13).

Inside the drum are blades that mix the grated cassava mass with water. The interior sheet is covered with an 80-mesh fabric or nylon sieve in which the grated cassava aqueous mass is strained. This sieve lets starch milk pass and retains the fiber.
Normal capacity of this mechanical sieve is 250–300 kg of wet grated cassava mass per hour.

Starch quality, in terms of fiber and debris content, depends on the sieve. Using 120-mesh or finer sieves will produce better quality starch.

Another model of this type uses four rollers. The transmission (drive pulley and shaft) spins on two rollers which turn the drum that is also supported by the other two rollers (Figure 26-14). The drum spins counter clockwise to the spin of the bearings. Except for this, this model is the same or very similar to the above-described model.

Sieving characteristics. Sieving is the slowest operation in the starch extraction process and is therefore its main constraint.

Fiber residue (byproduct). The byproduct generated by the sieving process is called fiber residue. After it has dried in the sun, it is used as feed supplements or as direct animal feed (Buitrago, 1990). A chemical analysis of this material indicates that dry fiber residue has a dry matter content of 80% to 85%, of which 60%–70% is
starch and 12%–14% is fiber. For instance, these figures are related to those obtained in the mass balance from Figure 26-21 for 1000 kg of fresh cassava roots. Thus, in the box titled “Fiber residue”, there is a starch content of 56.0 kg, which falls within the above-mentioned percentage:

\[
\frac{56.0}{90.1} \times 100 = 62.2\%
\]

Fiber residue production in the department of Cauca is figured to be 4500 t/year. This information was obtained by Gottret (1996) and through the cited survey.

Second sieving. In many cassava starch extraction plants, the starch milk is passed through small sieves after the main sieving process. The back and forth motion of these devices captures the fine fibers that might have been left over from the main sieving.

**Starch sedimentation**

Once the starch milk has passed through the sieve, it contains starch, fine fiber, and proteins in suspension. It is then directed into tanks or channels where the starch is sedimented out. It is from this starch milk, either flowing in channels or stagnating in tanks, that the densest component, the starch, whose different sized granules accumulate on the bottom, is separated.

In a channel system, this process can last up to 3 hours, yet in sedimentation tanks, it takes 6 to 8 hours. When this step is completed, there is a layer of compacted starch on the bottom (of the channel or tank). The supernatant water is discarded (read farther ahead).

**Sedimentation tanks.** There are 106 cassava starch extraction plants in the department of Cauca that use sedimentation tanks, which are made of brick and covered with tiles. The volume of water that passes through them per ton of fresh roots is 4.8 m³.

This amount of water, 5 m³ (500 L/100 kg of cassava), is also used to screen and sediment out 1000 kg of fresh roots (Figure 26-18).

The tanks are a rather large constraint to the process given the labor they require. Extraction plants do not actually have the proper number of tanks to handle their grated cassava production capacity. Moreover, the wait time for starch sedimentation on the bottom of the tank is 8 hours.

Tanks have two other disadvantages. First, they allow the starch to mix with the black starch and second they lose up to 2% of the sedimented starch when it is separated from that byproduct (a process called “desmanchar” in Spanish). In order to separate the two substances, the top layer of the sedimented starch must be cleaned using water and long handled squeegee (Appendix 1, Photo 26A-4).

**Sedimentation channels.** There are 100 cassava starch extraction plants in the department of Cauca that use sedimentation channel systems. These are covered with tiles or similar materials so the starch milk can flow. Channel length varies from 100 to 200 m, and it should be absolutely level to the floor. While the starch gradually settles, it forms a slight slope that helps the remaining starch milk to flow.

The recommended number of channels in a system is seven, each one measuring 25 to 30 m in length (Figure 26-15). These systems can be designed so as to adapt to the land topography (Appendix 1, page 516).

There should also be a grit chamber at the front of the channels where sand and other solids in the starch milk can accumulate.

The tiles make it so the starch milk flows evenly and without interruption, which will keep the black starch, sand (when there is no grit chamber), and other debris (fiber) in the starch from settling. If there are relatively large spaces between tiles, this will cause these starch contaminants to sediment.

When the sedimentation process has ended, there will be three layers in the channels and two different types of starch:

- The lower layer is the starch.
- The middle layer, called black starch, is a mixture of starch with proteins. Its thickness will vary.
- The top layer is the supernatant water or wastewater.

**Wastewater.** Wastewater is eliminated in the following manner:

- For tank elimination, pull out the plug from the drain pipe located near the base of the tank, a little higher than the level where the sedimented
starch layer usually ends (as the water flows out, it will carry away a little of the starch with it). If the plug is on the inside, it will have a string attached to help pull it out.

- For channel elimination, removing, one by one (from top to bottom), the four or five thin planks or hatches at the end of the last channel. As the level of starch milk rises during the sedimentation process, these planks, each measuring 60 x 8–10 cm (channel height is 40 cm), are placed one on top of the other.

With the removal of one large plank (60 cm x 40 cm) after the sedimentation process has been completed, the wastewater will exit the channel system, carrying with it a large part of the black starch and a decent percentage of the starch. Total wastewater volume of a channel system is around 50,000 L.

The channel system has the following advantages:

- Sedimentation in channels does not stop the benefit process, i.e. when the starch milk completes its flow through the system, the sedimentation is deemed complete and the next stage begins.

- To settle on the bottom, one starch grain must move 0.80 m in a tank and just 0.10 m in a channel. This difference explains, in large part, the above-mentioned advantage, specifically the speed of sedimentation.

When sedimentation is done in tanks, 2% of the starch is lost during the black starch separation stage. When sedimentation is done in channels, almost all the black starch exits with the wastewater such that very little of it accumulates as sediment on the layer of starch. During the black starch separation stage in the channel using the squeegee, there is no 2% loss of starch as there is in the tanks.

**Black starch (byproduct).** It is a byproduct of the starch production process, and it is obtained in this stage. The starch it contains is of low density, poor quality, and high protein content. It is used as pig feed and in glues (Alarcón 1994b).

Black starch production estimates for the department of Cauca are 750 t/year, as reported by Gottret (1996) and based on the above-mentioned survey.
Wastewater is left to sediment again in a tank (to separate the remaining black starch) and is later routed to rivers and streams. It may also be recycled for use in the washing process if water is a constraint and conserving it is convenient. It should be treated before disposal or recycling (see Appendix 4).

The starch that has settled on the bottom of the tanks or channels is subsequently directed to two places:

- The drying area, where it becomes natural or native starch for industrial and feeding purposes.
- Fermentation tanks, where it becomes sour starch for breadmaking after 20 to 30 days.

**Starch fermentation**

Fermentation is a natural process produced by amylolytic lactobacillus in anaerobic conditions (without oxygen in the environment). Cassava, a highly perishable agricultural product, it can be used best when conserved as fermented starch. This substance acquires special flavor, texture, odor, and leavening characteristics when baked that are desirable qualities for breadmaking and that cannot be found in native or unfermented starch (Figueroa 1991).

Sour starch is used in baking such breads as pandebono, pandeyuca, snacks, and others that have recently appeared in the markets and that are much sought after by populations living in different regions of the country (Pinto 1977).

**Fermentation process.** Sedimented starch is placed in fermentation tanks, and a thin layer of water is poured on top. There it is left for 20 to 30 days, a period that will vary depending on the region’s climatic conditions. The tanks vary in size, according to the extraction plant’s capacity (Figure 26-16), and are generally covered with wood on the inside.

Small tanks should be used for two reasons: (1) they are easy to fill and (2) they simplify the daily drying operation.

The necessary inoculant for fermentation can be the water that has been used in the fermentation process for several days or a piece of already fermented starch or even some dampened residual fiber spread over the top layer of starch in the tank.

The supernatant water (3–4 cm higher than the starch) is left in the tanks to maintain the anaerobic state. Filled tanks are protected from the sun by damp residual fiber or wet polypropylene bags, thereby preventing the water from evaporating (see Appendix 1, Photo 26A-5). In very hot zones, the fermentation tanks should be buried.

Fermentation time is variable and depends on the ambient temperature.

One method of checking the fermentation is through its pH level, but this type of control is not practiced in the cassava starch extraction plants. The pH at the end of the process will be between 3.5 and 4.0.

**Starch drying**

Starch needs to be dried before it can be used. Native starch can be sun-dried or oven-dried, but sour starch can only be sun-dried. After fermentation, the starch is removed from the tanks or channels in compacted blocks and then transported to the drying patios where it is exposed to sunlight.

The blocks are milled to help the drying process, this being done by hand or with a drum grater that is covered on the inside with screws or nails and that “pulverizes” the starch blocks before drying.
It is then spread out in 1-2 kg/m² layers on black polyethylene bags since they absorb large amounts of sunlight and thus contribute to rapid and uniform drying. In these conditions, 1 t of starch will need approximately 1000 m² of drying space. That area is, consequently, another constraint that clearly affects several of the cassava starch extraction plants considering they are located in regions whose topography is very rugged.

Starch can be dried on trays or sliding trays (Figure 26-17) built into the factories' roofs or above their floors (see Appendix 1, Photo 26A-6).

Starch drying requires roughly 6 hours in the sun in Colombia. The product is removed very gently 2 to 3 times during that period with rakes made from a pliable material so as not to damage the plastic. During the operation, winds will carry off starch dust, which leads to losses (0.7% in dry base) that are extremely difficult to avoid.

**Final treatment of the starch**

When the moisture content of the starch is between 12% and 14%, it is collected from the drying area. While it dries, the starch again forms relatively hardened lumps that must be milled and sieved.

The lumps are milled using the drum graters described above in the drying process. Sieving, on the other hand, is done with a mesh (100–120 mesh), whose caliber will depend on the desired results.

After being sieved, the starch is loaded in woven polypropylene sacks.

**Yield**

Figure 26-18 shows a flow chart summarizing the sour starch extraction process as it is carried out in La Agustina extraction plant located in the department of Cauca. The final quantity of starch in the flow chart is based on what 1000 kg of fresh MVen 25 cassava variety would produce. Another study was conducted recently to compare efficiency of Vietnamese and Colombian technologies for cassava starch production at low rural level (Da et al. 2012).

**Quality**

Breadmaking potential (BP) is the main criterion in sour starch quality. BP is defined as the capacity of the starch to leaven during baking. It is not possible to reach uniform quality with artisanal sour starch production, and this fact, consequently, hinders its access to market.

BP primarily depends on the variety of cassava and the fermentation and sun-drying processes of the starch. The choice of suitable varieties and proper management (and control) of both production processes would greatly improve sour starch quality (Dufour et al. 1996).

Studies have been conducted on the relationship between fermentation inoculant microflora and starch quality. Some starch producers use, as the inoculant in their fermentation tanks, water from a different tank in which high quality starch was produced. Also compared were results from sun-drying and oven-drying at different temperatures and under UV light (Brabet et al. 1996).

Sour starch quality improves when the layer of water in the fermentation tank (3–5 cm) guarantees anaerobic fermentation, lactic acid production (specific amylolytic bacteria strains), and a drop in pH to 3.5. In an oven that controls starch moisture and that bathes the starch in UV light, its quality could be improved to greater levels because starch extraction plants could uniformly dry their product. Unfortunately, it is not possible to achieve the same BP as with sun-dried starch.

Further studies have been performed that examined the influence of cassava type and root storage time on sour starch quality as well as the effect produced by the overall climate and water used in the production process (Brabet et al. 1996).
Sour cassava starch in Colombia

Marketing

Sour and native (sweet) starches are sold mainly through agents. In Cauca, these agents transport the product to Santander de Quilichao, a town in the northern sector of the department. Once there, they sell it to other agents, who then transport it to Colombia’s major cities. Of the 210 cassava starch extraction plants in the Cauca department, 35 directly sell their product to bakeries, 20 sell it through the Cooperative Association of Extraction of Cauca (COAPRACAUCA), and the rest deal with agents.

General recommendations

For cassava starch extraction plants. Several years of research on cassava starch extraction plants in the department of Cauca, provides enough experience to recommend certain machinery, methods, and designs (Chuzel et al. 1995a). Nevertheless, each plant is a specific case, and any recommendation should be
tailored to fit their infrastructure and their owners’ economic limitations.

**Traditional extraction plants.** These are labeled Type 1 processing plants (see above description), whose capacity ranges between 800 and 1000 kg of roots every hour.

1. The washer/peeler used in this extraction plant operates on a cycle-by-cycle (models 1 and 2), and operators lose time during each loading/unloading pass. These machines should be changed to a *semi-continuous* washer/peeler (see Figure 26-10B, model 3) because it simplifies the operation and also increases plant’s capacity to 800 to 1500 kg of roots per hour.

2. Mechanical graters that feature four bearing housings (Figure 26-14) have certain drawbacks:
   - Overloading the machine is not a good idea since it will shut down or detach itself from the drive pulley.
   - Starch can become contaminated with rust or bearing grease because the starch milk can come in contact with the rollers. These should, therefore, be substituted for *‘hanging’* or half-shaft sieves (Figure 26-13) since these do not present that problem. Additionally, the fabric or mesh that is outside the sieves should be finer (120-mesh) to be able to retain the fiber that passes through the sieves. This fiber affects starch quality.

3. Starch milk sedimentation capacity is the largest constraint to any starch extraction plant, and it depends upon the system used for sedimenting the daily production.
   - If sedimentation tanks are used, the capacity is limited by the number of tanks the plant has available. Likewise, the black strach and the starch mix together in the tanks, thus lowering starch quality to average.
   - If *sedimentation channels* are used, then the operation is non-stop. Also, the water carries off the less dense material (black strach) and leaves cleaner the starch on the bottom since the black starch does not mix with it.
   - Channels can be of different length. An important recommendation to keep in mind is that they have to be absolutely level to the ground and designed with ends that are curved or rounded so the starch milk does not strike the channel walls, thereby creating turbulence from the counterflow in which the black starch and the starch mix together.

4. Plant owners should carefully think about making the change from a system built on flat terrain to one that uses gravity to move the product. The change is so costly that it would mean making over the entire starch extraction plant.

5. If there are frequent power outages in the region where the extraction plant operates and if the cassava is not processed for hours or days, then a gas powered engine should be installed besides an electric backup plant.

6. The belts that drive the engines (transmission) are very dangerous. It is recommended installing them on just one side of the processing plant and to use protective shields around them to reduce risks.

7. For more industrial safety, then install several gear motors (one for each machine that may need it) instead of running all the equipment off just one engine alone (electric or gas powered). The cost of this improvement is high.

For a Type 1 cassava starch extraction plant to increase its production, the following measures should be taken:

- Install an additional sieve.
- Increase the number of sedimentation tanks or build a channel system.
- Increase the number of fermentation tanks in relation to daily production.
- Increase the drying area.

**Improved cassava starch extraction plant.** These are called Type 2 (see process description above). They use a channel system and have streamlined their operations by harnessing the terrain’s slope (Chuzel et al. 1995b).

1. These starch extraction plants can improve their drying operation through installing a pulverizing mill to crumble or “break apart” the compacted starch. After being crumbled, the starch can be spread easily, quickly, and uniformly.
2. The water that runs through the channels can be recycled to wash cassava roots, thereby making more water available in the plant which will increase the speed and efficiency of the washing operation and the overall process. Figure 26-19 shows the ideal blueprint of a Type 2 starch extraction plant.

New cassava starch extraction plant. When planning to build a new extraction plant model, called a Type 3, the following should be kept in mind:

- Must use good quality and abundant water throughout the process: close to 30 m³ per day.
- Water temperature must be below 25 °C (fresh water).
- It is recommended that the effluents from the sour starch production process be treated so they do not contaminate nearby streams. If the wastewater cannot be treated, then it should be directed to an area far from the extraction plant that would, therefore, be at a lower level on the terrain.
- The plant should be built at a site where gravity, due to its topography, can be harnessed for the process. The difference between the plant’s highest and lowest points should be 3.5 m, making it possible to conduct the starch production process with the help of gravity. The system will facilitate a semicontinuous flow of operations at a lower cost.
- Fermentation tanks should be buried so that the top is at the same height as the upper part of the channels.
- Water from the last channel can be directed to flow around the tanks to keep their external temperature constant.
- If the chosen site is on flat terrain, it is still possible to raise the grating operation to the proper height (building a metal structure and using a conveyor belt) to create a system by gravity artificially.

The drawing of a new, Type 3 plant with all the above described starch extraction processes can be seen in Figure 26-19.

Comparative yield. The following table compares the processing capacity of the three models (in tons of fresh roots per month) and the extraction efficiency, which is the relation (in weight) between the processed roots and the starch extracted from them.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Plant Capacity (t/month)</th>
<th>Ratio (by weight) roots: traditional starch</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Rallanderia” Traditional</td>
<td>20</td>
<td>5.5:1</td>
</tr>
<tr>
<td>Improved</td>
<td>30</td>
<td>5.0:1</td>
</tr>
<tr>
<td>New</td>
<td>50</td>
<td>4.5:1</td>
</tr>
</tbody>
</table>

Thus, building a plant with greater capacity means improving its starch extraction capabilities. Moreover, profitability of the extraction process noticeably depends upon the level of starch extraction.

For input management.

Water. 10,700 t of starch is produced in the department of Cauca each year. Processing each kilogram of starch requires 31 L of water, or an annual amount of 332,000 m³, which is equivalent to the amount of contaminated water a town of 10,000 inhabitants would generate yearly.

The water used in the starch extraction process comes from a variety of sources and has the following characteristics:

- Lake, river, gully, or surface well water is usually contaminated with organic matter and microorganisms.
- Spring water normally has low mineral content and is very good for this process.
- Deep well water, compared with water from surface wells, is free of organic matter and microorganisms because it is purified as it filters through the different soil layers.

However, an underground well can become contaminated by abandoned septic tanks, gutters, and sewers. Contaminated water has been known to travel great distances through veins of limestone and other porous materials to end up polluting streams.
Figure 26-19. Descriptive plan of an ideal, well established extraction plant that graphically shows the sour cassava starch extraction process. The above figure shows the roofed version of this plant. Part of this design is currently being used in some plants in the department of Cauca (for example, the CETEC Totoyuca plant in Siberia, Caldono).
Therefore, a **natural filter** should be built for water used in the extraction process and designed with layers of thick gravel, fine gravel, and clay, which will reduce the minerals and solids suspended in stream, river, and well water (Rojas et al. 1996) (see Appendix 4).

Water that has been used in sedimentation channels is usually directed into **tanks** close to the factory for its subsequent transport to a water treatment plant. When the water is not dumped into a natural stream, it can be used again for the cassava washing process, which translates into a savings of nearly 17% in water consumption for the entire extraction process (Colin et al. 2007).

**Raw material.** The quality of the cassava is essential for extracting an important percentage of high **quality** starch that has elevated breadmaking potential (dough rising while baking). It is therefore vital to select the cassava variety to be grown wisely for the roots that will be processed.

**Machinery.** All machines in the plant should be placed in such a way so that the product moves with the help of gravity. This layout will improve production capacity, use less work area, and allow all machines to run on just one engine, thereby making the process very economical.
Appendix 1:

Graphic Description of the Starch Extraction Process

The photographs show the methods used in different regions (such as Cauca and Caldas). Please note the development of the process, from the traditional to the mechanized system.

Photo 26A-1. Washing cassava roots with the feet.

Photo 26A-2. Grating washed cassava roots.

Photo 26A-3. Continuous sieving of the grated cassava using a worm screw.

Photo 26A-4. Sedimented starch in tanks (the worker is separating the black starch).

Photo 26A-5. Starch fermentation in tanks.

Photo 26A-6. Fermented starch drying in the sun.

Figure 26-20A. Traditional system (type 1) to extract cassava starch.
Sour cassava starch in Colombia

Figure 26-21A. Mechanized system (types 2 and 3) to extract cassava starch.

Photo 26A-7. Sacks of cassava arrive at the extraction plant.


Photo 26A-9. Grating the washed roots.

Photo 26A-10. Sieving the grated cassava mass.


Starch production is a major world agroindustry, with a volume of around 33 million tons per year, of which just 3.8 million (11.4%) comes from cassava. The rest is from corn (21.2 million), potato (1.96 million), wheat (2.01 million), rice (0.05 million), and sweet potato (4.17 million) (Ostertag, 1996).

**Appendix 2:**

**Industrial Use of Cassava Starch**

**Food industry**

Natural starch (also known as native, sweet, or industrial) is used, by itself or in a blend, to make macaroni and different flours. These are subsequently used to make puddings, baked goods, cookies, wafers, sponge cake, creams, ice creams, soups, salads, sausages, and other food products. Fermented starch (sour) is used to make traditional Colombian food products like pandebono and pandeyuca (Figure 26-22A).

- Native starch can be changed through physical means into pregelatinized starch (PG starch), which has the property of being soluble in water without first having to be cooked.
- It is used as a thickener, stabilizer, or glaze on fruit pies, dry mixes, puddings, and milk cream. Adding PG starch improves the texture and appearance of these and other, similar products.
- Native starch can also be changed through chemical means into a food industry product used as a thickener in white sauce and a stabilizer and emulsifier in salad dressings, nutritious gelatins, instant dessert mixes, ice creams, pudding, and baby food. Depending on how it is changed, it can be used in the paper, adhesive, and other industries (Balagopalan et al. 1988).

**Paper industry**

Native starch used in the paper industry is called unmodified starch (UM starch). There are three operations in its treatment process: (1) refining (or screening), (2) purifying (strictly industrial operation), and (3) drying.

**Paper and cardboard.** Producing paper and cardboard is a multi-step process and, in one (or more) of them, UM starch is added to the final product to give it certain properties and different grades of quality.

- The paper industry requires three basic characteristics from cassava-based UM starch: (1) whiteness, (2) low fiber content, and (3) few impurities. The starch may have other physical or chemical characteristics that affect the papermaking or slurry production process.
- UM starch helps the cellulose fibers bond and forms a top layer that reduces fuzz and increases the individual sheet’s consistency, solidity, and durability. This thin layer also improves cardboard’s strength of material.
- UM starch is also used as an adhesive for laminating certain papers, corrugated cardboard boxes, wall paper, cardboard tubes, and other articles. It is also used in paper and cardboard recycling.

**Glues.** UM starch is the raw material for making the basis of inexpensive glues or adhesive products.

- These adhesives are used to make such disposable products as packing materials, stickers, wrapping paper, and label/envelope glue.
- These inexpensive glues are very useful for high speed packing machines and labelers for two reasons: relative low cost and high gluing speed.
**Organic decomposition.** UM starch used in the paper industry lasts 3 to 4 days without decomposing, at which time it becomes fermented by different microorganisms.

This fermentation produces gases (whose foul odor is not immediately smelled) and denaturalizes the UM starch, thereby altering its properties, primarily losing 25% of its adhesive capacity, reducing its viscosity, and changing its acidity (pH).

Therefore, anti-bacterial substances should be added to UM starch to keep the lactic acid-producing and coliform bacteria, as well as fungus (genera Penicillium and Aspergillus and yeasts), from growing.

**Textile industry**

UM starch is the most abundant and inexpensive ingredient, and thus the most important, in different textile glues.

**Warp sizing.** The textile industry prefers (almost exclusively) to use UM starch for two reasons: (1) it is the only substance that can treat very white fabrics and (2) it degrades less than starches made from other sources. Fabrics can be sized temporarily or permanently.

- Temporary sizing is when starch is applied to warp yarns just before these are turned into fabric so that they are stronger, softer, smoother, and more flexible. The sizing agent is deposited as a film on, and totally covering, the warp threads.

- This process keeps the threads from unraveling, tangling, spotting, and breaking, any of which would seriously disrupt the textile making process.

- Permanent sizing is used in fabric finishing and is relatively stable since it remains on the fabric at least until it is in the hands of the consumer.

- The fabric is impregnated with starch, which improves its texture, increases the surface brightness, gives it “body” and solidness to help in its handling, increases the “weight”, the print quality, and the overall appearance and feel of a good quality fabric.

**Pharmaceutical industry**

PG starch is used to dilute, to glutinate, to lubricate, or to disintegrate different solid products. It also helps absorb, gives viscosity, and acts as a vehicle for pasty, liquid, or semisolid substances in dermatological creams and lotions.

It is furthermore used to make fine facial, compact, and nutritional powders, and as raw material in making wafers (Balagopalan et al. 1988).

**Other uses**

UM cassava starch is used in the chemical industry to make alcohol, glucose, acetone, explosives, colorants, dry batteries, and dental impressions as well as to coagulate rubber.

The mining industry uses it as a flocculating agent and a component in oil drilling solutions.
 Appendix 3:  
Cassava Starch Extraction Plant Costs

**Construction and set up**

Table 26A-1 shows the infrastructure and equipment costs of a Type 3 starch extraction plant with a 30-t monthly production capacity (300 t/year for 10 months of operation).

**Operating costs**

A cassava starch extraction plant with the equipment listed in the above table generally operates at 80% of its capacity, thereby producing annually 250 t of sour starch. Operating costs, however, are estimated on its basic capacity (30 t/month) and expressed in United State Dollars (US$1.00 = Col$1450; from September 1998).

1. Cost of producing 1 t of dry starch:

   **Fixed costs**
   - Administration (US$351.00/month) US$11.75
   - Plant maintenance 3.55
   - Depreciation (Per unit produced. See below) 1.70
   
   Subtotal (ST1) 17.00

   **Variable costs**
   - Labor (3 shifts, US$5.53/shift) 16.60
   - Electricity (2 kW/hour, US$0.20/kW) 0.40
   - Water (Natural streams, no cost) —
   - Packaging (20, US$0.35/unit) 7.00
   - Miscellaneous costs 7.00
   - Freight cost 17.20

   Subtotal (ST2) 48.20

   **Total** (operating costs/t) = ST1 + ST2 US$65.20

2. Cost of producing 30 t (1 month of operating)

   US$65.20/t x 30 t/month = US$1956/month

3. Yearly depreciation:
   - Equipment and machinery service life = 10 years
   - Salvage value (junk) = US$300
   - Production over course of service life = 250 t/year x 10 years = 2500 t
   - Accounting period = 1 year

   Applying the formula:
   
   Dep./t = \( \frac{\text{US$4500} - \text{US$300}}{2,000 \text{ t}} \) = US$1.70 per ton produced

   Dep./Month = US$1.70 x 30 t = US$51 per month in operation
   Dep./Year = US$1.70 x 250 t = US$420 per year in operation

   These costs were updated in 2012 (Da et al. 2012).
**Sour cassava starch in Colombia**

Table 26A-1. Cassava starch extraction plant costs (values from September 1998).

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Machinery and equipment for the process</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava washer/peeler (2 t of roots/hour)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>Cassava grater (2 t of roots/hour)</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>(300 kg of grated cassava mass/hour)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>x 2</td>
<td>2,000</td>
</tr>
<tr>
<td>Reciprocating screen&lt;sup&gt;c&lt;/sup&gt;</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Motorized pulverizing mill (1.5 kg/hour)</td>
<td>700</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td>4,500</td>
</tr>
<tr>
<td><strong>Plant infrastructure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedimentation channels (each 30 m x 60 cm x 40 cm)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>x 7</td>
<td>15,000</td>
</tr>
<tr>
<td>Starch drying patio (2000 m², 8 cm thick)</td>
<td></td>
<td>18,000</td>
</tr>
<tr>
<td>Fermentation tanks (1.5 m³)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>x 20</td>
<td>15,000</td>
</tr>
<tr>
<td>General civil engineering work (400 m³)&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
<td>10,000</td>
</tr>
<tr>
<td>Factory cover or roof&lt;sup&gt;g&lt;/sup&gt;</td>
<td></td>
<td>6,000</td>
</tr>
<tr>
<td>Starch warehouse (30 m³)</td>
<td></td>
<td>8,000</td>
</tr>
<tr>
<td>Black starch deposit tank (30 m³)</td>
<td></td>
<td>8,000</td>
</tr>
<tr>
<td>Fiber residue deposit tank (15 m³)</td>
<td></td>
<td>4,000</td>
</tr>
<tr>
<td>Power transmission</td>
<td>700</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td>84,700</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>89,200</strong></td>
</tr>
</tbody>
</table>

<sup>a</sup> Different washer/peeler models yield this amount.
<sup>b</sup> Model: Intermittent mechanical.
<sup>c</sup> For second sieving.
<sup>d</sup> Covered in tiles.
<sup>e</sup> Covered in tiles and wood.
<sup>f</sup> Columns, walls, floors, and drains.
<sup>g</sup> Bamboo and zinc, mainly.
The cassava starch extraction process consumes large quantities of water and produces effluents that have considerable negative impacts on biotic systems when directed into surface streams. From an economic and technical viewpoint, anaerobic systems and, in particular, biodigesters are an important alternative for treating these types of effluents.

This appendix will present and evaluate a normal digester and a digester complemented by aquatic plants.

Background

Wastewater from the sedimentation stage of starch extraction is the main environmental problem of that process. On average, a cassava starch extraction plant can produce somewhere between 20 and 30 m$^3$ of wastewater per day, depending on the level of technology used and the hours in a work day.

According to the studies conducted by Rojas in 1992, and reported in Rojas et al. (1996), this wastewater has considerable pollution capacity because it carries large amounts of particulate organic matter, possesses moderate acidity, and contains small quantities of the cyanogenic ion (CN$^-\$).

Several studies have found (Duque 1994) that this type of effluent biodegrades at 70% for an insoluble sample and 92% for a soluble one. The 8% of the matter resistant to biodegradation is probably inorganic.

Extraction process effluents show OCD$^5$ values between 3000 and 7000 mg/L. The Sanitary Engineering Department, Universidad del Valle, has conducted different studies that show the feasibility of purifying wastewater when using anaerobic digestion systems, examples being the two-phase reactor and the upflow sludge blanket reactor.

Reactor evaluation

In 1997, the Corporación para Estudios Interdisciplinarios y Asesoría Técnica (CETEC) set up anaerobic treatment systems in three cassava starch extraction plants in Santander de Quilichao, Cauca, that dump their wastewater into the Mandiva River.

The reactor constructed in these factories was a tank digester supplemented with an aquatic plant system, and their performance evaluation was conducted by the Universidad del Valle Environmental Sanitation Department, the results of which were published in the thesis titled: “Evaluación del desempeño de dos biodigestores en el tratamiento de las aguas residuales del proceso de extracción de almidón de yuca” [Performance Evaluation of Two Biodigesters for Treating Wastewater from the Cassava Starch Extraction Process] and presented by Javier A. Manrique M. from the Chemical Engineering Department in June 1999.

Study objectives were:

- Setting up and operating a pilot treatment system.
- Evaluating system performance by measuring the percent of organic and solid matter removed.
- Determining the necessary conditions for adapting the biomass to the substrate and for guaranteeing the system's routine operation.

Its main conclusions were:

- Under the conditions in which the reactor operated, the largest drop in OCD was 76.6% and solid removal was 61%. These values were recorded for a 21 hour hydraulic retention period, as illustrated in Table 26A-2.
- It is not possible to assert that tank digesters are not a suitable alternative for treating wastewater from the cassava starch extraction process. If the operating parameters of the reactor were very strictly controlled, particularly pH (which should be

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4. Industrial Engineer, Rural Agro-industry, CETEC, Cali, Colombia.
5. OCD = Oxygen Chemical Demand. The amount of oxygen a determined volume of effluent requires for chemical degradation of the organic matter it contains. OCD is the amount of oxygen for microbiologically degrading the organic matter in an effluent.
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between 6.7 and 7.4), then it would be possible to achieve highly satisfactory results with it.

• To maintain wastewater pH within the optimal range for anaerobic digestion, it is necessary to have a system that allows an alkalizing solution to be continuously and proportionally introduced into the managed substrate flow. Calcium and sodium hydroxide returned good results in that area.

• If the alternatives sought out for treating wastewater have to be within reach of social sectors with limited access to technology and financial resources, then it is worth improving these types of reactors since the infrastructure costs are very low.

Tank digester description and set up

This system was set up in two cassava starch extraction plants in the northern sector of the Department of Cauca. Both dumped their wastewater into the Mandiva and Quinimayo basins. Each digester is comprised of two dual layer polyethylene heavy duty polyethylene tanks, 2.5 m in diameter, with additives to protect against acids and UV light. The tubes are buried in different pits with a cross-sectional area of 3 m². Both ends of the tubes are connected and completely sealed to concrete boxes that are the affluent inlet and effluent outlet. A sludge evacuation system is attached to the bottom part and a biogas outlet at the top.

Digester design parameters are:

• Average affluent flow: 2.7 m³/hour
• Minimum hydraulic retention period: 21 hours
• Required volume: 57 m³

Given these parameters, digester construction requires these elements:

• 2 pits, 16 m long, with a net cross-sectional area of 3 m² and real cross-sectional area of substrate occupation of 2 m².

• 2 dual layer, heavy duty polyethylene tanks, 2.5 m in diameter and 20 m long.

• 2 brick inlet boxes, 1.0 m³ and 0.70 m high, with a 12” diameter concrete tube.

• 2 brick outlet boxes, 1.0 m³, with a 12” diameter concrete tube.

• Sludge evacuation system and biogas routing and use system.

Table 26A.2. Tank digester operating results from a 1999 evaluation conducted by the Universidad del Valle.

<table>
<thead>
<tr>
<th>Parameter (units)</th>
<th>Value Affluent</th>
<th>Value Effluent</th>
<th>Removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.7</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>OCDₜ (mg/L)</td>
<td>3806.17</td>
<td>890.23</td>
<td>76</td>
</tr>
<tr>
<td>OCDₚ (mg/L)</td>
<td>3012.58</td>
<td>816.12</td>
<td>79</td>
</tr>
<tr>
<td>TSS (g/L)</td>
<td>0.58</td>
<td>0.23</td>
<td>61.15</td>
</tr>
<tr>
<td>VSS (g/L)</td>
<td>0.52</td>
<td>0.21</td>
<td>60.34</td>
</tr>
</tbody>
</table>

a. OCDₜ = total oxygen chemical demand (includes algae in M.O. contents)
OCDₚ = soluble oxygen chemical demand (excludes algae)
TSS = total suspended solids (in the effluent, for example)
VSS = volatile suspended solids (in the effluent, for example)
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To save space, the acronym “CIAT” is used instead of “Centro Internacional de Agricultura Tropical”.


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