CHAPTER 23

Production and Uses of Refined Cassava Flour

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Introduction

Rapid urban growth in Latin American and Caribbean (LAC)[3] countries has increased demand for processed food, opening opportunities whereby the cassava crop can acquire higher added value. In Colombia, public and private entities are highly interested in the potential prospects of increasing the consumption of cassava and its derived products. Accordingly, several agroindustrial projects on cassava are being promoted in various parts of the country. One dynamic market is animal feed, where cassava flour or dried chips can be used as an energy source in balanced feed formulas.

However, to be viable, agroindustrial cassava projects need other alternative marketing options for using cassava, for example, as a partial substitute of other products such as wheat, maize, and rice flours, and even sweet cassava starch. Thus, cassava can participate in food-processing and industrial markets, for which products of higher added value can be developed.

CIAT has conducted projects to expand the production of cassava flour and its use, thus promoting the opening of new markets and establishing rural agribusinesses that offer small farmers opportunities for increasing their income.

In 2006, CLAYUCA, with financial support from the Ministry of Agriculture and Rural Development of Colombia (MADR, its Spanish acronym), implemented the project *Establishing a pilot plant for the continuous production of refined cassava flour*. The aim was to develop a technology to extract, on an ongoing basis, refined cassava flour with high starch contents and low contents of fiber, ash, and protein (García et al. 2006).

A modular pilot plant was therefore established to continuously produce refined cassava flour. Mechanical means (mill sieves) and pneumatic classification (cyclones) were used to obtain granules as fine as those of starch. Specifically, flour was refined to a maximum fineness, where particles were less than 50 μm in particle size.

The project was based on the problems industry has with cassava starch such as the generation of large amounts of wastewater to obtain native starch. Studies were initiated, with the collaboration of Universidad del Valle (Colombia), to obtain flours based on dried cassava chips, using a minimum quantity of water (Barona and Isaza 2003).

The pilot plant

Dried cassava chips can be ground into high-quality flour for use as a partial substitute for wheat, maize, rice, and other flours in foodstuffs such as breads; pastas; flour mixtures for pies, beverages, and soups; extruded products; and processed meats. Cassava flour can also be used as raw material in the production of glues for corrugated cardboard boxes, biodegradable plastics, beer, and ethanol.

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8. For an explanation of this and other acronyms and abbreviations, see *Appendix 1: Acronyms, Abbreviations, and Technical Terminology*, this volume.

Figure 23-1 shows the pilot plant for the continuous production of refined cassava flour located in the facilities of CIAT, Palmira, Colombia. The plant processes 300 kg/h of dried cassava chips. The design took into account the different issues determining the functionality of processing dried chips into refined flour. A simple technology was used, in which elements were easy to manage and accessible for maintenance. The technology was simple enough for anyone person with minimal training to carry out. Furthermore, the plant permitted variation in operating conditions, according to the desired refining requirements such as refined flour or a much finer flour. The pilot plant was used:

Figure 23-1. The CLAYUCA modular pilot plant for producing refined flour from dried cassava chips, Palmira.

- To generate materials or raw materials for the research and development of new products
- For the technical training of functionaries
- To manage actual costs of operation and profitability
- To disseminate a new technology to cassava-processing companies interested in products of higher added value, and to companies wanting to enter new markets, using cassava flour in their processes.

Principal components

Figure 23-2 details the basic procedures for extracting refined cassava flour. It shows a screw conveyor for feeding raw material (dried cassava chips) to the mill sieves, three cylindrical mill-sieves with three shafts and three cylindrical sieves (screens), three fans, and five cyclones for pneumatic classification and flour collection.

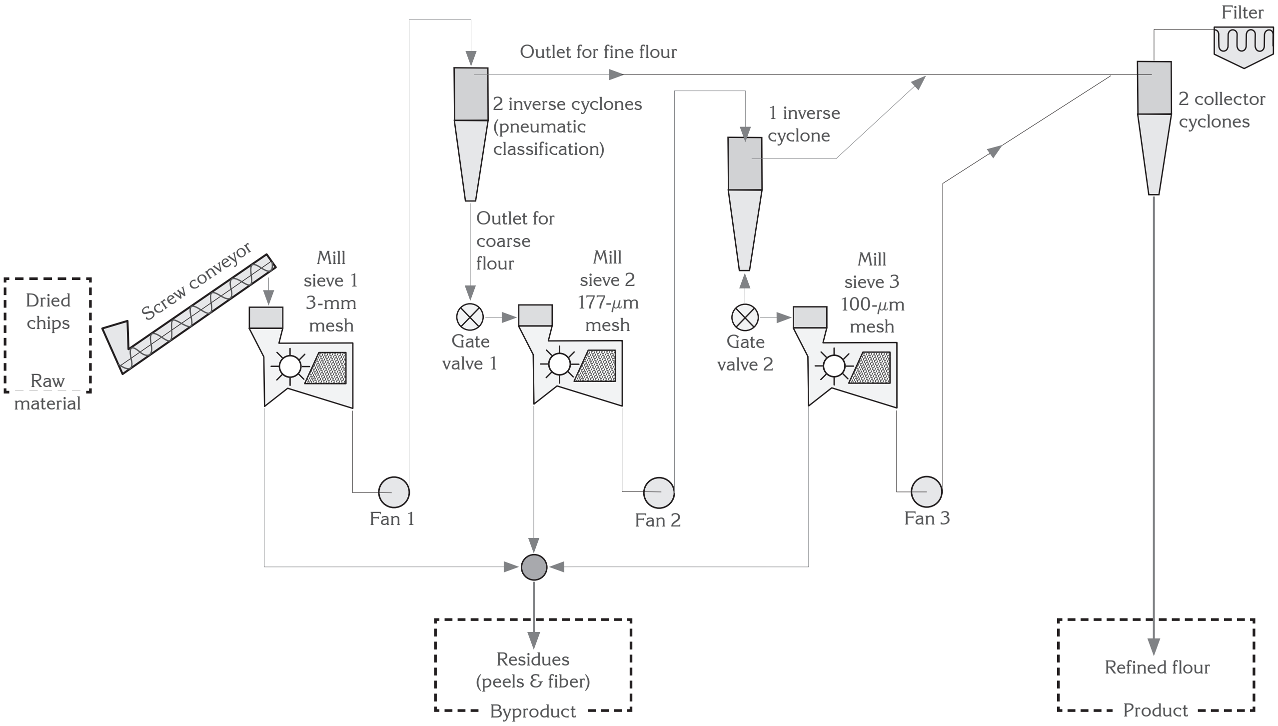

Figure 23-2. Diagram showing basic procedures for extracting refined cassava flour at the CLAYUCA pilot plant, Palmira.

Screw conveyor. The feeder or screw conveyor consists of a receiving hopper with a capacity of 300 kg/h of dried cassava chips (Figure 23-3). The chips are deposited into the hopper and conveyed by the screw to the first mill sieve for processing. At its largest, the screw's diameter is 6 inches. The shaft diameter is 2 inches, and the space between the blades is 4.5 inches.

Cylindrical mill-sieves. Each mill sieve—a fundamental part of the plant—consists of a feed hopper, a cylindrical estructure or body where the sieve and shaft are located, and a discharge hopper with a cylindrical outlet that couples to a fan (Figure 23-4).

Mill shafts. Each of the three shafts measures 1½ inches diameter, 170 cm length and possesses an endless screw at one end to feed dried cassava chips into the sieve. It also transmits energy for the blades striking the chips. The four stainless steel blades are joined to the shaft and are located at 90° to each other. They are designed to strike the chips over the mesh, exercising sufficient strength to mill them and separate the peels from the flour (Figure 23-5).

Figure 23-3. Screw conveyor-feeder.

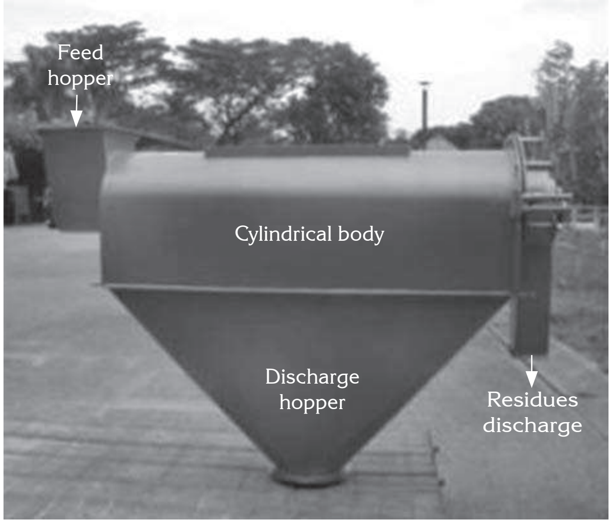

Figure 23-4. Mill-sieve.

Cylindrical sieves. The sieves are built with an expanded mesh of ⅛ inch to form the structure of the screen, with stainless steel rings coupled to its ends, comprising a cylinder of 29.5-cm diameter and 120.5-cm length. The screens are covered with mesh of 3 mm for grinding and 177- or 100-μm for classification of the particles (Figure 23-6).

Fans. The fans transport fine flour from the mill sieves' outlets to the collector cyclones. The pilot plant has three centrifugal fans with radial blades and a 12-inch-diameter rotor (Figure 23-7).

Collector cyclones. The pilot plant has five cyclones, two of which collect fine particles, in this case, of refined cassava flour. The other three classify the particles. The basic structure of a collector cyclone

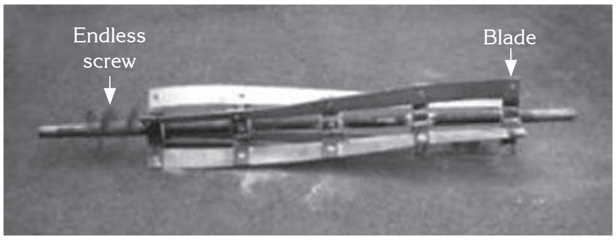

Figure 23-5. A mill shaft.

Figure 23-6. Sieves for milling and classification, with mesh openings of, from left to right, 3 mm, 177 μm, and 100 μm

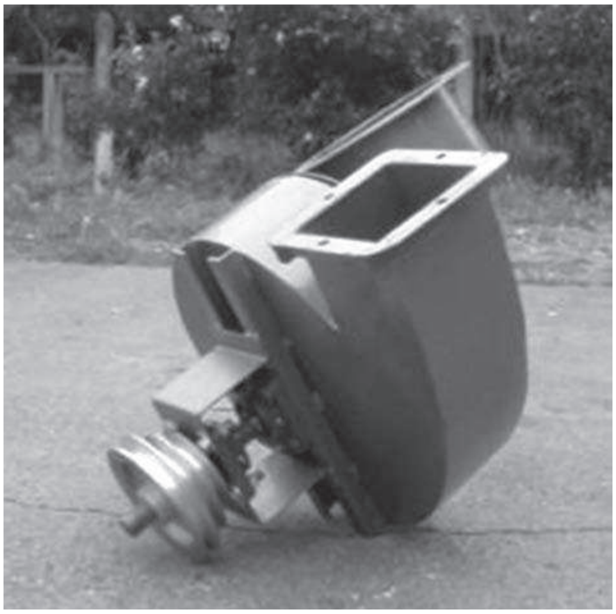

Figure 23-7. Centrifugal fan.

comprises a vertical cylinder with a conical base. It is provided with a tangential inlet, normally rectangular, and a circular discharge for clean air in its upper parts. This equipment is designed to separate particles from a fluid current, with high efficiencies for particles larger than 20 μm.

The cyclone's tangential inlet creates centrifugal forces that tend to push particles towards the equipment's periphery, away from the inlet of the air, thus increasing sedimentation and making collection more effective (Figure 23-8).

Classifier cyclones. These are used to separate fine from coarser particles. It is characterized by an inverse feed (central axial) that differs from that used in conventional cyclones. Studies by CLAYUCA (García 2006; Herrera et al. 2007) determined that, as air loaded with particles flowed into the equipment, in an axially central direction, it moved in different directions in three areas inside the cyclone (Figure 23-9).

- The first area, marked as A in Figure 23-9, constitutes the entire periphery of the cylinder's conical part. The larger particles decant parallel to the axial feed, losing speed and becoming deposited into the cyclone's bottom.

- In area B, a back pressure is formed, which helps disperse the particles entering the cylinder's upper part.

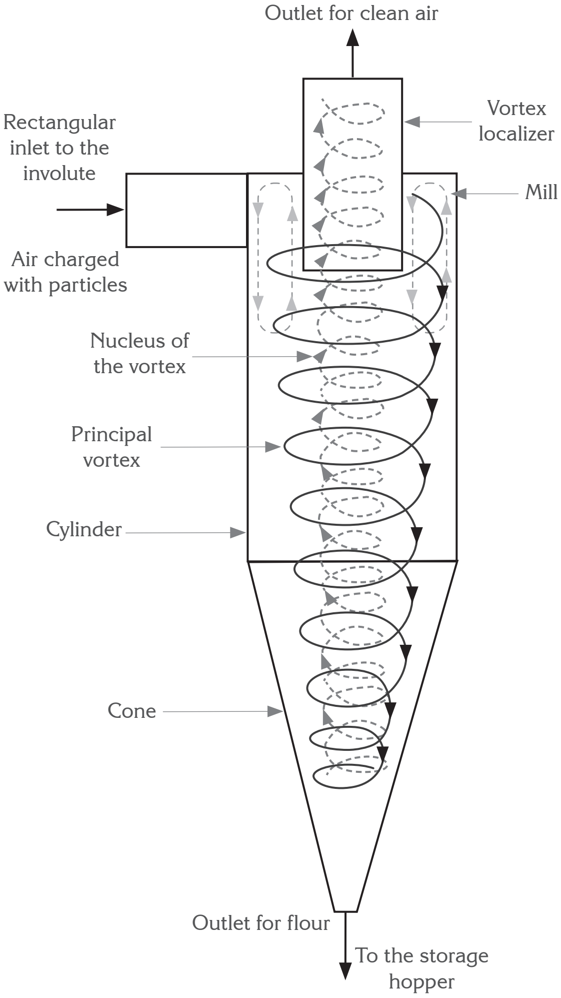

Figure 23-8. Collector cyclone.

- Area C lies in the cyclone's cylindrical part where the air, loaded with particles, flows inside, in an axially central direction. Meeting the back pressure from area B, this air forms considerable turbulence, which lifts the finest particles and forces them to leave the cyclone by a duct connected tangentially to the collector cyclone.

Refined cassava flour production

The stages of refined cassava flour production in the pilot plant are shown in Figure 23-10. The basic stages are feeding dried cassava chips for mill-sieving in mill 1. The resulting coarse flour is then mill-sieved in mill 2 to create an intermediate flour that is then mill-sieved in mill 3. The flour is classified in the three classifier cyclones and the final refined flour is then collected by the two collector cyclones.

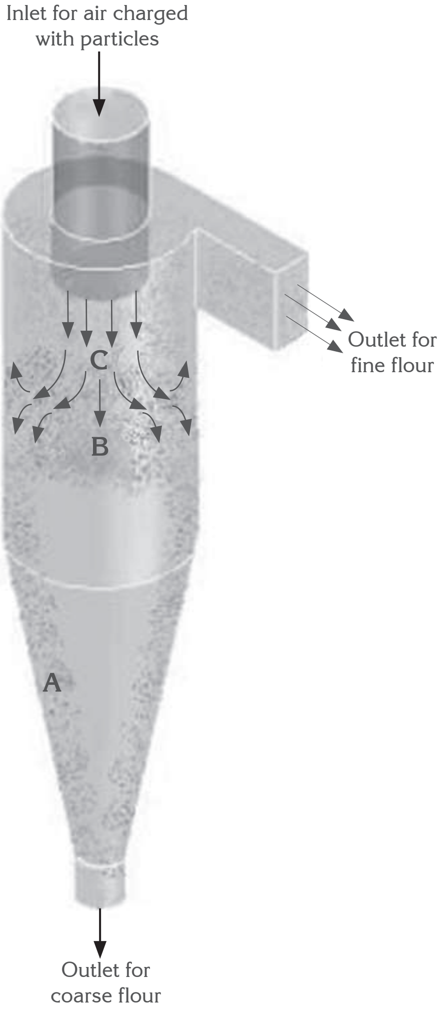

Figure 23-9. Classifier cyclone.

Feeding the dried cassava chips. Unpeeled dried cassava chips with a moisture content between 10% and 12% are deposited in the hopper by a screw conveyor to feed the first mill sieve. The feed capacity is 300 kg/h of dried chips, which are, ideally, free of peduncles.

First mill-sieving. Dried cassava chips are fed to the first mill sieve, which has an expanded mesh with 3-mm openings. The chips are reduced in size and, according to the mesh's openings, separated into small pieces of peel, thin outer peel, and fiber that comprise the residues. These are extracted as byproducts that are usually converted into animal feed. Material that succeeds in passing through the mesh is extracted by fan 1, which transports it to the classifier cyclones. After pneumatic separation, the flour produced by mill sieve 1 is divided into two types: fine flour that rises directly to the collector cyclones, and coarse flour that is decanted through a gate valve and automatically becomes the raw material for the next stage.

Second mill-sieving. In this stage, the coarse flour from the first mill sieve becomes the raw material for mill sieve 2, which has a mesh with 177-μm openings. In this mill, the flour is again reduced in size, and new residue is generated. Flour that passes through the mesh is extracted by fan 2 and separated into two new flours within the classifier cyclone, that is, intermediate flour that is decanted and becomes the raw material for the third mill sieve, and fine flour that is directly collected.

Third mill-sieving. As with the previous stages, intermediate flour from the second mill sieve enters the last stage of milling and refining in mill sieve 3. This mill has a mesh with 100-μm openings. The refined flour is extracted by fan 3 and transported to collection. Again, new residue is generated.

Pneumatically classifying the flour. Classification is carried out during the intermediate stages of mill-sieving. Conventional cyclones are used, that is, those that are normally used to collect processed products. As they already meet the requirements for classifying particles, the cyclones are being used as pneumatic classifiers.

An air current, loaded with flour, is fed inversely into the cyclone, making possible the decanting of coarse particles (>100 μm) towards the mill sieve for further milling. The fine particles, however, leave the cyclone by its tangential outlet to be later collected. They thus avoid being re-milled.

Collecting the refined flour. The refined flour is collected by two cyclones with tangential feed inlets that are connected in parallel for greater flour capture. The two cyclones are coupled to a cone that discharges the end product into packing bags.

Conversion factors

The CLAYUCA pilot plant obtained an average conversion factor of 1.3:1. That is, for every 1.3 kg of dried chips (12% moisture content) that entered the equipment, 1 kg of refined flour was extracted, and 0.3 kg was either byproduct or residues.

If refined-flour production from fresh roots is considered, the conversion factor would range between 3.6:1 and 4:1, depending on the cassava roots' dry matter content. That is, for every 3.6 or 4 kg of fresh cassava, 1 kg of refined flour is extracted.

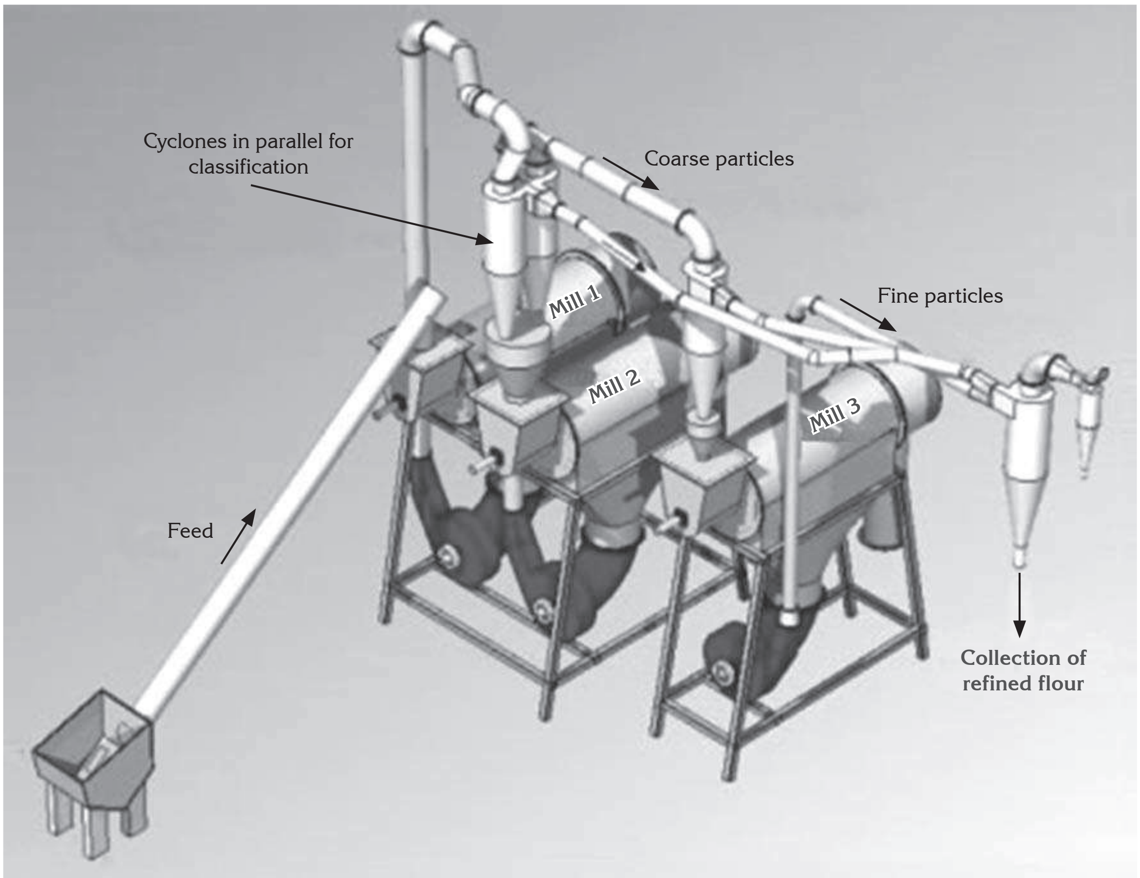

Figure 23-10. Production of refined cassava flour at the CLAYUCA pilot plant, Palmira, Colombia.

Physicochemical description of refined cassava flour

Granule analysis. As mentioned earlier, two types of products are extracted from each mill sieve in the pilot plant: refined flour as the principal product and three types of residues, which form the byproduct. These materials are separated out in the equipment, eliminating any peel that was left over from the manual peeling of cassava roots for dried chip production. This was one of the pilot plant's most valuable contributions to refining, because it eliminated the need for labor (and therefore costs) to peel roots destined for processing into flour for human consumption.

Table 23-1 lists the overall results of several granule analyses of the refined flour obtained at the CLAYUCA pilot plant. The refined flour had a high percentage of impalpable particles (90% at less than 50 μm). Even so, in this same equipment and using only the first two stages of mill-sieving, flour of bread-making quality could be obtained. This flour had the following characteristics: 70%–75% of particles at less than 50 μm and 20%–25% of particles at less than 177-μm. Although less refined, the flour has important applications in the baking, brewing, meat-processing, and ethanol-producing industries.

Table 23-1. Granulometric analysis of the refined cassava flour produced by the CLAYUCA pilot plant.

Mesh openings (μm)	Fraction retained (%)
150	2
106	3
50	5
<50	90

Chemical composition. Table 23-2 shows the average composition of materials present in the production of refined cassava flour from dried chips. The composition of native starch is provided for comparison. The table shows that processing dried cassava chips in the pilot plant leads to reductions by

Table 23-2. Typical composition of materials present in the production of refined cassava flour. The composition of native starch from the same cassava variety is also included.

Materials	Crude protein (%)	Ash (%)	Crude fiber (%)	Ether extract (%)	Starch (%)
Dried cassava chips	3.0	3.5	4.0	0.8	77.0
Refined cassava flour	1.4	1.3	1.9	0.6	85.0
Residues	5.5	6.5	52.0	1.0	24.0
Native starch	0.1	0.1	0.3	0.1	91.0

more than 50% in values for crude protein, ash, and crude fiber. The values for native starch (extracted from the same cassava variety) show significant differences with those of the refined flour, affecting various properties, as described below.

Rheological properties. The rheological characteristics of refined cassava flour were evaluated, using amylographs or profiles of flour slurries, in which changes in the viscosity of a suspension of flour and water are recorded during heating and cooling (Rodríguez et al. 2006). Figure 23-11 shows the viscosity curves, as generated by a viscograph, of refined flours from cassava varieties M Col 1505, M Per 183, and HMC-1, and a commercial cassava starch.

The viscosity curves show that, compared with the commercial starch, all the refined flours presented lower gelatinization temperatures and lower maximum viscosities. Moreover, the maximum viscosity peaks for the flours were not reached as rapidly. This indicates that the commercial starch is easier to cook and requires less energy for cooking. Table 23-3 also presents the results for the following parameters: ease

Table 23-3. Viscosity profiles of refined flour and native starch, both obtained from cassava variety HMC-1. Evaluations on were carried out with a viscoamylograph RVA series 4.

Parameter[a]	Refined flour	Native starch
Gelatinization temperature (°C)	63	65
Maximum viscosity (RVA units)	146	478
Ease of cooking (min)	4.4	1.6
Gel stability (RVA units)	72	332
Gelatinization index (RVA units)	14	54

a. RVA units measure viscosity according to the Rapid Visco Analyzer.

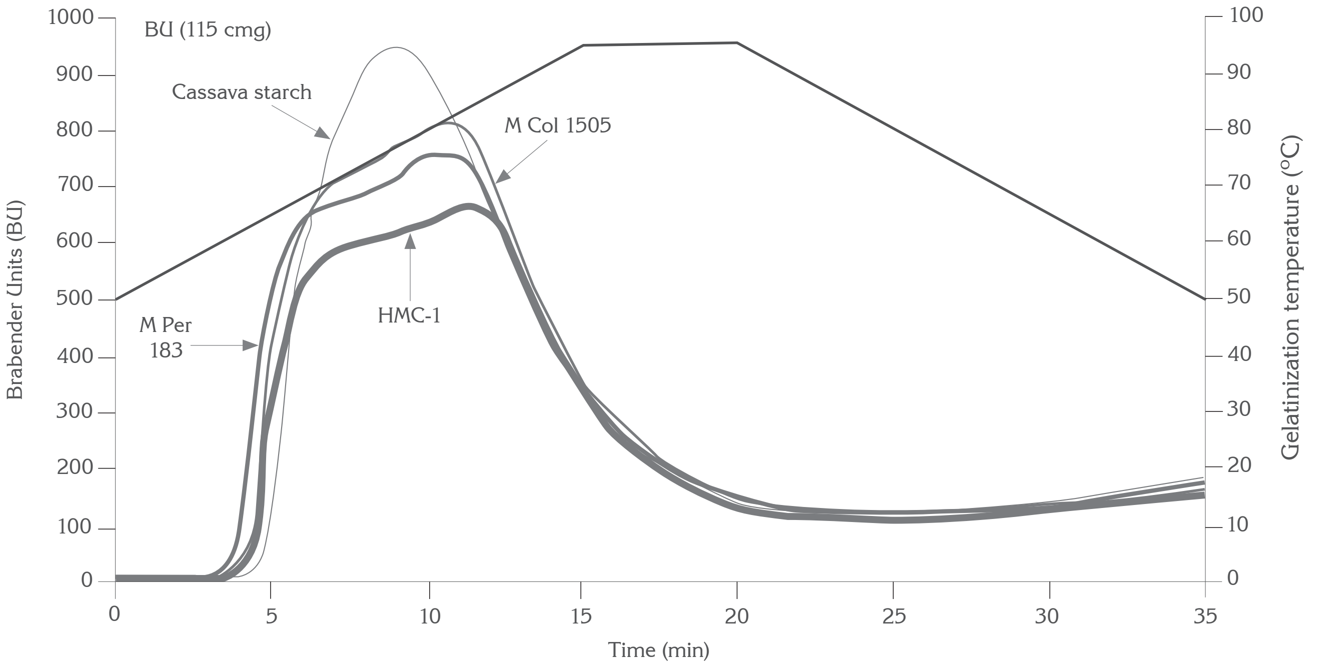

Figure 23-11. Micro-viscoamylograph (MVAG) profiles for flours from different cassava varieties, compared with commercial cassava starch.

of cooking, gel stability, and gelatinization index or gelling for both the refined flour and the native starch extracted from the same cassava variety (HMC-1).

Flour was easier to cook than starch, as confirmed by a slower swelling rate of granules for the refined flour. With regard to gel stability (which is related to the fragility and solubility of swollen starch granules), the native starch presented a value of 332 RVA units, suggesting that the refined flour tended to form more stable gels than did the native starch. Finally, during testing in the RVA viscoamylograph, the value for the gelatinization index of the refined flour indicated that pastes formed with cassava flour are stable, with little tendency towards retrogradation.

Uses of refined cassava flour

Table 23-4 presents possible applications of refined cassava flour in different food products and industrial use, as determined by recent research carried out by CLAYUCA. These studies showed that bread prepared with refined cassava flour, using 5% and 10% levels of substitution, performs well in tests for specific volume and presents high values of water absorption. No significant differences were found for acceptance by consumers, compared with pure wheat bread (Aristizábal and Henao 2004). Partial substitution of cassava flour also enabled bakers to save on production costs, as cassava flour can be obtained at lower prices than wheat flour.

Because of its starch's capacity to thicken during final preparation, refined cassava flour is an excellent raw material for beverage and soup preparation. This characteristic also allows cassava flour to be used as an ingredient in meat processing, as it improves water retention and bite characteristics. Refined flour can also be used in extrusion to produce dietary pastes, snacks, and breakfast cereals (flakes).

All types of composite flours can be used to prepare instantaneous beverages and infants' beverages (Ospina et al. 2009). Tests also confirmed that cassava flour can replace or complement the various raw materials used in extruded products, widely used in human food.

For industrial use, refined cassava flour is an appropriate raw material in the manufacture of glues for affixing corrugated cardboard boxes, even though levels of fiber, ash, and protein are not as low as those of native starch. Refined flour nevertheless also has potential because it has characteristics similar to those of pearl maize starch (Bonilla and Alonso 2002).

In 2006, CLAYUCA analyzed the technical viability of including refined cassava flour as a brewing additive. Results indicated that refined cassava flour is a technically viable alternative for maltose as a raw material in beer production (Ospina and Aristizábal 2006).

Finally, in collaboration with the Universities of Cauca and Valle, research has been carried out on the production of thermoplastic biopolymers from cassava flour. These polymers can be used as precursors in the manufacture of biodegradable plastics (e.g., bags, linings, and disposable utensils). The largest difference between the plastics currently produced (based on petroleum derivatives) and those based on cassava flour is that the latter is completely biodegradable. This means that its usability as packaging, from its production, is no more than 1 year (Villada and Acosta 2003).

Table 23-4. Applications of refined cassava flour.

Market	Product	The raw material replaced	Percentage of substitution	Advantages of cassava flour
Foodstuffs	Bread	Wheat flour	5–20	Lower cost
	Mixtures for beverages and soups	Flours from wheat, rice, maize, and plantain	10–40	Increased yield
	Processed meats	Wheat flour, starches	50	Better quality
	Snacks	Wheat, rice, and maize flours	100	Lower cost
	Beer	Maize starch, rice flour, maltose syrup	50–100	Lower cost
Industrial uses	Glues	Maize and potato starches	30–100	Lower cost
	Biodegradable plastics	Maize and potato starches	70	Better structural stability

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Technological Study of Cassava Flour in Bread-Making

Johanna A. Aristizábal and Sergio Henao

Introduction

In Colombia, as in many South American countries, an acute imbalance is growing between the production and demand for wheat to supply domestic needs for bread flour. Among the factors causing this imbalance are lack of land suitable for growing the cereal, relatively low yields, population growth, and increasing per capita consumption of wheat and its derivatives. This imbalance has been compensated only through importing large quantities of the cereal at increasingly higher prices, thus generating an expensive outflow of foreign exchange from the country.

To help resolve this situation, much effort has been focused on the partial substitution of wheat flour with indigenous crop flours. Solutions towards incorporating raw materials of local origin (cassava, rice, maize, sorghum, and millet) into popular foods such as bread and pastas have been studied. Several studies examined the use of cassava flour as a wheat flour substitute in bread-making. In Colombia, such studies have shown promising results. From a technical viewpoint, breads comparable with those of traditional wheat breads and substituting as much as 15% with cassava flours can be produced (Aristizábal and Henao 2004; Henao and Aristizábal 2009).

The Government's strategy of promoting the cassava crop, complemented with efforts to link farmers to new markets for cassava, will help promote the sustainable cultivation of the crop. Thus, new employment opportunities in rural areas will be created, benefiting cassava flour producers, increasing the offer of this product, and reducing wheat flour imports. Furthermore, bread-makers will have a more economical substitute for the traditional raw material. About 60% of wheat flour is destined for bread-making. Hence, if 10% were replaced with cassava flour, imports would be reduced by about 75,000 t of wheat flour per year.

Although cassava flour contains a low percentage of protein (~2%), one of its important contributions is its higher fiber content (>3%), compared with wheat flour with less than 1%. Cassava flours, which can provide a bread with a high fiber content, are convenient for bread-making in a society concerned with good health and nutrition.

Bread-making tests

Three processing variables were defined: cassava variety, percentage of substitution, and bread type, with three levels for each. The cassava varieties—CMC-40, M Col 1505, and HMC-1—were selected for their availability, average yield of dry matter in roots, dry matter content, and HCN content. The percentages selected for substituting wheat flour with cassava flour were 5%, 10%, and 15% (w/w ratio, based on quantity of wheat flour). These values were chosen from the literature, which reported that values of more than 15% affected the bread's final quality. White bread types selected were *rolls, sandwich,* and *hamburger*, the selection being based on previous studies, which had selected the most used bread types—rolls and sandwich—for evaluation.

The bread-making trials were based on the typical formulas used for rolls, sandwich, and hamburger breads by the bakery "La Estrella" located in Palmira, Colombia. To avoid modifying the preparation protocols that its workers followed daily, only the percentages of substitution by cassava flour were included in the traditional mixture. For each trial, 1 kg of wheat flour was used with its respective percentage of substitution according to cassava variety and bread type, and always preparing a 100%-wheat bread as control. The stages of bread manufacture are illustrated in Figure 23-12.

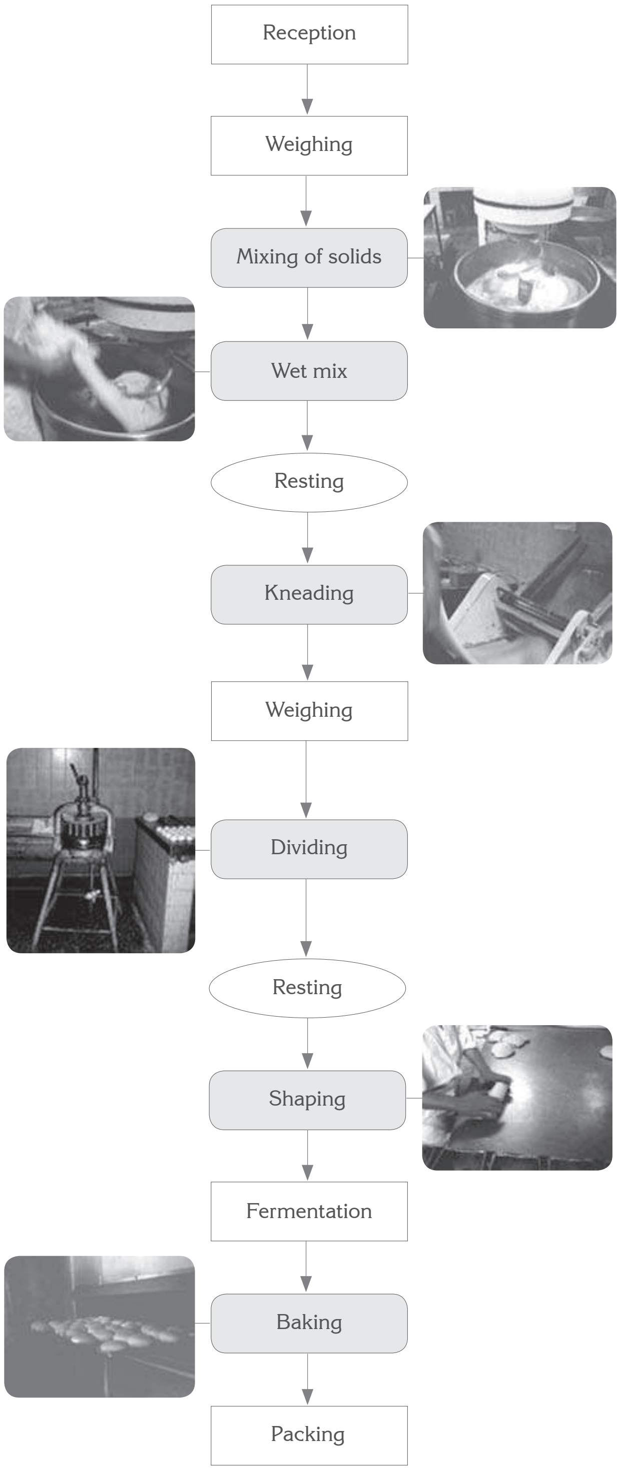

Figure 23-12. Flow chart for bread production at a large bakery in Palmira.

The bread types were prepared according to the proportions of components in the formula, fermentation time, and baking temperature and time. Thus, bread rolls was divided mechanically for later shaping. This type of bread required a fermentation chamber with a constant feed of steam at 30 °C for 1.5 h. The bread was then baked at 200 °C for 25 min.

Sandwich bread was also divided, but manually, and the dough then shaped and introduced into rectangular molds that gave the breads their characteristic form. Fermentation was carried out in closed molds at room temperature, not in the fermentation chamber. The bread was then baked at 190 °C for 45 min.

Hamburger bread was divided mechanically before the dough was fermented in the chamber. The dough was then rested for about 20 min to soften before being kneaded to facilitate shaping. The hamburger breads were baked at 200 °C for 25 min.

The formulas used to prepare rolls, sandwich, and hamburger bread are listed in Table 23-5.

Analyzing cassava flour

Cassava flours obtained at the CLAYUCA pilot plant were evaluated, using microbiological, granulometric, and physicochemical analyses (Table 23-6). The cassava flours obtained met microbiological requirements and possessed the granule size required by the Colombian Technical Standard for wheat flour (NTC no. 267, as established by ICONTEC). More than 98% of particles passed through the mesh with 212-μm openings.

The water-absorption index for cassava flours was higher than for wheat flours. This factor favors the former's use in bread-making, as increased water absorption means that more bread will be obtained for the same quantity of flour. The water-solubility index was also higher for wheat flour, which was expected, as wheat flour presents a higher content of soluble proteins in water.

Table 23-5. Formulas for rolls, sandwich, and hamburger breads at a large bakery in Palmira.

Component	Percentage[a]		
	Bread rolls	Sandwich bread	Hamburger bread
Wheat flour	85–100	85–100	85–100
Cassava flour	5–15	5–15	5–15
Yeast	4	4	6
Sugar	12	8	12
Salt	2	2.5	2
Margarine	12	6	6
Water	50–60	50–60	50–60

a. Percentages given, assuming 100% as flour.

Table 23-6. Physicochemical characteristics of wheat and cassava flours.

Analysis[a]	Flours from cassava variety:			
	CMC-40	M Col 1505	HMC-1	Wheat
Dry matter (%, wb)	89.20	92.03	91.61	89.02
Moisture (%, wb)	10.80	7.97	8.39	10.98
Protein (%, db)	1.78	2.32	1.34	14.01
Crude fiber (%, db)	3.45	3.21	2.96	0.84
Starch content (%, db)	86.00	87.00	88.25	69.00
Ash (%, db)	2.06	1.26	2.25	0.72
Cyanide, total (ppm)	6.58	9.30	13.00	—
Cyanide, free (ppm)	0.58	1.15	0.58	—
Reducing sugars (%, db)	1.73	2.30	1.37	0.94
Amylose (%, db)	12.02	12.15	12.31	13.87
Amylopectin (%, db)	87.98	87.85	87.69	86.13
WAI (g of gel/g of flour)	4.35	4.73	4.15	3.11
WSI (%)	7.01	7.43	8.79	13.26

a. Abbreviations wb refers to wet basis; db, dry basis; WAI, water-absorption index; WSI, water-solubility index.

Rheological analyses of wheat-cassava composite flours

Doughs made from wheat-cassava composite flours, using three substitution percentages, were evaluated. Testing involved a farinograph (Table 23-7), alveograph, amylograph, falling number test (Table 23-8), mechanical work, and water absorption during the process.

Except for flours made from variety HMC-1, water absorption by all composite wheat-cassava flours was, on average, 1% more than water absorption by wheat flour. The growth period for wheat flour is almost double that of wheat-cassava composite flours. This factor indicates that dough prepared from wheat-cassava composite flours reaches consistency in less time.

Results for flour stability presented major differences between varieties, showing a ratio that is inversely proportional to the percentage of substitution. Composite flours with a 15% substitution showed less tolerance of kneading.

The degree of decay of composite flours is higher than that of wheat flour. In contrast, the time to breakage for all composite flours was shorter than for wheat flour. This was expected, as this period indicates the strength of gluten in bread flours. Wheat flour therefore presents the highest resistance to breakage.

Table 23-7. Characteristics of composite flours according to a farinograph.

Composite flour[a]	Water absorption[b]	Dough peak time (min)	Stability (min)	Degree of decay (FU)[c]	Break-down time (min)
Wheat only (control)	63.8	3.9	17.1	11.0	18.0
Wheat+CMC-40 (5%)	64.4	2.3	16.7	23.0	10.3
Wheat+CMC-40 (10%)	64.5	2.0	10.5	39.0	4.5
Wheat+CMC-40 (15%)	64.5	2.2	9.4	48.0	3.6
Wheat+M Col 1505 (5%)	64.3	2.7	9.3	37.0	6.0
Wheat+M Col 1505 (10%)	64.7	1.9	3.0	60.0	2.9
Wheat+M Col 1505 (15%)	64.6	1.9	3.3	47.0	2.8
Wheat+HMC-1 (5%)	63.1	2.9	17.4	25.0	12.1
Wheat+HMC-1 (10%)	63.4	2.0	14.0	37.0	4.8
Wheat+HMC-1 (15%)	62.9	1.7	3.7	53.0	2.8

a. Percentages indicate levels of substitution of wheat flour with cassava flour.
b. In mL/100 g of flour.
c. FU refers to farinograph units.

Table 23-8. Characteristics of composite flours in terms of an alveograph, falling number test, and amylograph.

Composite flour[a]	Strength (joules)	Tenacity[b]	Extensibility (mm)	Balance	Falling number (sec)	Tgel (°C)	Vmax (cP)
Wheat only (control)	381.87	147.40	60.80	2.42	353	59	77.40
Wheat+CMC-40 (5%)	400.96	152.90	56.00	2.73	360	66	77.45
Wheat+CMC-40 (10%)	280.30	152.90	41.49	3.69	354	68	76.90
Wheat+CMC-40 (15%)	339.55	152.90	48.20	3.17	354	68	77.90
Wheat+M Col 1505 (5%)	295.28	154.00	50.70	3.04	343	61	77.65
Wheat+M Col 1505 (10%)	335.63	151.47	45.05	3.36	349	63	77.35
Wheat+M Col 1505 (15%)	284.49	151.80	39.77	3.82	329	68	76.90
Wheat+HMC-1 (5%)	372.98	152.90	54.00	2.83	349	70	76.92
Wheat+HMC-1 (10%)	301.03	152.90	43.20	3.54	324	74	77.85
Wheat+HMC-1 (15%)	272.13	143.66	46.30	3.10	325	74	76.95

a. Percentages indicate levels of substitution of wheat flour with cassava flour.
b. In water (mm).

The values of strength in flours made from variety HMC-1 tended to be inversely proportional to the percentage of substitution. However, composite flour with 5% substitution of flour from variety CMC-40 had a higher strength value than wheat flour. The tenacity values for all composite flours were similar to each other and surpassed, by a low percentage, that for wheat flour. This datum reflects what was observed during the process, that the tenacity of doughs made with composite flours was greater. Extensibility of doughs made with composite flours were less than that of wheat flour.

The balance of doughs from wheat-cassava composite flours presented values that were higher than those of the control and showed differences between themselves. In the bread-making tests, problems occurred during kneading and in the bread's final appearance for flours from varieties HMC-1 (10%), M Col 1505 (15%), and CMC-40 (10%), when these were prepared as sandwich bread, as the composite flours presented the highest balance values.

The "falling number" values obtained for all composite flours presented acceptable values, falling into the requisite range of 250 to 400 seconds. Bread flours should not present values of more than 400 seconds, as they would require the addition of enzymes, thus inducing prolonged fermentation times and creating breads with pale crumbs.

Gelatinization temperatures (Tgel) of composite flours are higher than for wheat flour. Starch granule size affects Tgel. In wheat flour, this ranges between 2 and 38 μm, whereas, in cassava flour, it ranges between 5 and 35 μm. Hence, wheat flour presenting smaller granules may reach Tgel in less time.

Wheat flour presents constant viscosity over time once it reaches maximum viscosity. In contrast, cassava flours tend to continue increasing in viscosity over time after reaching maximum viscosity, thus demonstrating higher instability, compared with wheat flour. Composite flours tend to form more stable gels, whereas cassava flour of the same variety, after being gelatinized and reaching maximum viscosity, tends to continue increasing in viscosity over time.

Composite flours need to absorb more water during processing, the need increasing as the percentage of substitution increases. This fact is verified by the higher value of water absorption that composite flours presented during the farinograph test (Table 23-7). Composite flour made from variety M Col 1505 required the largest volume of water.

Analyzing prepared breads

Prepared breads (Figure 23-13) were evaluated for their specific volume, shelf life, and sensory tests of acceptance (aroma, crumb texture, flavor, and acceptability).

To evaluate the presence of mold, four samples of each treatment were stored in individual polyethylene bags, under the same conditions (away from direct light, moisture, and sources of contamination) and at room temperature. While the breads did not harden, most samples showed mold 7 to 9 days after preparation. These values were closely similar to those obtained for wheat bread, which showed mold after 9 days.

Results also indicated that an inverse ratio exists between the percentage of substitution of wheat flour and specific volume. The specific volumes of breads prepared from composite flours with substitutions of 5% and 10% were higher than that of wheat bread. All breads prepared with 15% of substitution presented lower specific volumes than wheat bread. Flour from variety M Col 1505 performed best in the specific volume tests.

The sensory tests included 50 surveys (hedonic test) to evaluate four samples (the three percentages of substitution and the control) from each variety. The surveys were directed at people who regularly consumed bread. They ranged in age from 14 to 70 and in social strata from 2 to 6. The people surveyed only made one evaluation, so that panelists were not repeated in the evaluation.

Results suggested that bread prepared from composite wheat-cassava flour from variety M Col 1505 did not present differences in acceptability to consumers, whether for aroma, flavor, crumb texture, and general acceptability. As a result, this variety produced flour with the best baking quality of the three varieties evaluated. The 5% substitution was the most acceptable overall, presenting an equal scoring or higher than the control. The 15% substitution presented the lowest values for most of the tests.

Bread rolls performed best in the acceptability tests as, according to the consumers, it presented minimal or no differences to wheat bread, probably because this type of bread had the highest amounts of fat and sugar in its formula. These factors helped mask the effects of including cassava flour. The lowest values were for the hamburger bread, where flours from most of the varieties did not please the respondents. This bread had the fewest ingredients in its formula, which meant that the effects of adding cassava flour were more noticeable.

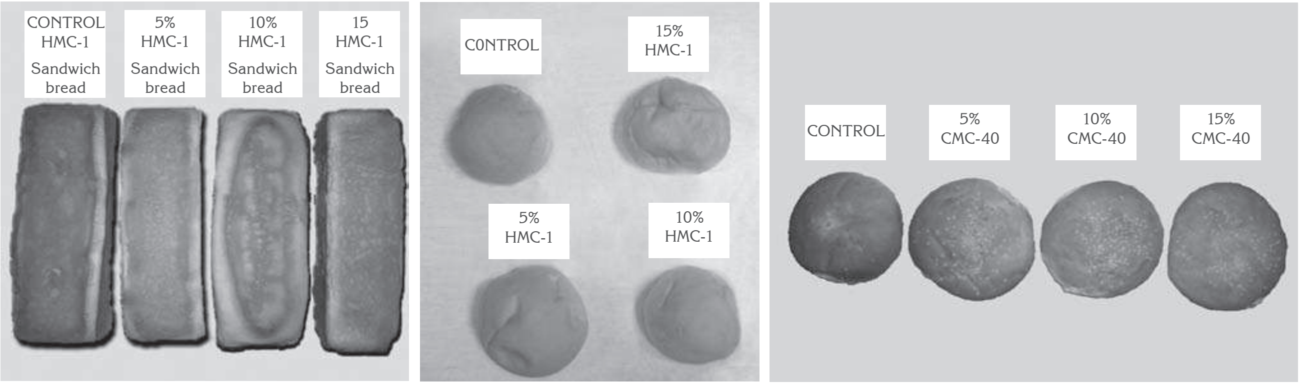

Figure 23-13. Samples of sandwich, rolls, and hamburger breads prepared with composite flours, substituting 5%, 10%, and 15% of wheat flour with cassava flour.

Conclusions

The microbiological quality of cassava flour can be improved by ensuring prior cleaning of the washing and chipping equipment and drying trays. This should be followed by efficiently washing cassava roots, immersing them for 20 min in tanks containing sodium hypochlorite at 20 ppm.

From a technical viewpoint, the use of wheat-cassava composite flours at 5% and 10% substitution is feasible and advantageous, as these present characteristics that are indistinguishable from those of wheat bread.

Of the cassava varieties used to manufacture bread from wheat-cassava composite flour, M Col 1505 performed best in the specific volume tests, had the highest water absorption values, and did not present differences of acceptability to consumers in terms of aroma, flavor, crumb texture, and overall acceptability. As a result, flour from this variety presents the best baking quality of the three varieties evaluated, particularly when a 5% substitution is used.

Economic indicators determined that, for the processing conditions of a large bakery such as the one in which the experiment was developed, savings obtained by using a 10% substitution were about US$8,055 per year (US$1.00 = Col$1800 in 2010).

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Glues from Dry-Extracted Cassava Starch for Use with Corrugated Cardboard

Ana Milena Bonilla and Lisímaco Alonso

To identify new products and options for marketing cassava, and as part of CLAYUCA's research and development activities, research was developed to analyze the technical and economic viability of producing glues from refined cassava flour and thus replace certain starches used in the glue industry.

Cassava starch is traditionally extracted by means of a "wet" process (Chuzel 1991), where polluting effluents are generated that are mostly discharged into rivers and other sources of water for the rural areas where starch-extraction agribusinesses are located. Moreover, in most of these regions, water is limited and does not have the quality needed for preparing a quality product.

A "dry" process needs to be found for obtaining cassava starch without generating polluting effluents (Garcia 2006; Garcia et al. 2006; Herrera et al. 2007; Barona and Isaza 2003) while producing a quality product that is competitive in price for use in glue manufacture. Such a process would help reduce negative environmental effects; and give industries another source of raw material for their products, thus helping them to reduce costs of importing raw materials. In particular, the "dry" process would help strengthen the role of the cassava crop as a source of employment, foreign exchange, and income for the country's cassava-producing sector.

This feasibility study handled issues such as extraction of refined flour and production of ultra-refined flour, which is known as "dry" starch (testing five selected cassava varieties). Several formulas for making two types of glues were also evaluated and compared with commercial glues (Bonilla and Alonso 2002).

Preselecting cassava varieties

To produce ultra-refined flour (with <100-μm diameter particles), five cassava varieties were preselected from the elite clones group in the germplasm bank held at CIAT (Improved Cassava Project). Criteria were amylose content, viscosity, high field production, and high starch yield. The varieties were HMC-1 (ICA P-13), CM 6740-7 (Reina), M Per 183 (Peruana), CM 523-7, and M Col 1522 (Venezolana). Table 23-9 provides the values of these varieties' principal characteristics.

High amylose content generates an effective glue as an end product. As the glue dries, the amylose aligns, forming a rigid layer. Furthermore, it permits rapid evaporation of water on union, thus producing faster drying, that is, the amylose molecules tend to reassociate. Fast drying is an important characteristic for glues used to seal cardboard boxes.

Amylose also fulfills a very important task in the glue's penetration into the paper or cardboard (Skeist 1977). Amylose is a polymer, able to recrystallize the starch after gelatinization, a process known as retrogradation. This is significant for the end product's stability and conservation.

Table 23-10 records data from amylographs of native or raw starches extracted from the previously selected varieties.

As this project began, Cartón de Colombia showed interest and offered a sample of maize pearl starch, a raw material used to make glues for different applications. This starch was characterized in terms of its proximal composition and was compared with different cassava flour samples. Table 23-11 lists the compositions of the different ultra-refined flours and maize pearl starch in terms of percentages of protein, crude fiber, fat, ash, moisture content, and starch.

Table 23-9. Characteristics of cassava varieties preselected for the production of "dry" cassava starch.

Variety	Yield (t/ha)	Dry matter (%)	Amylose (%)
HMC-1	20–22	34	24
CM 6740-7	20–28	36	15
M Per 183	25–40	32	22
CM 523-7	18–26	36	21
M Col 1522	10–25	29	23

Table 23-11. Proximal analyses of ultra-refined cassava flours, types 1 and 2, and maize pearl starch.

Identification	Protein (%)	Crude fiber (%)	Fat (%)	Ash (%)	Moisture (%)	Starch (%)
Flour type 1						
HMC-1	4.6	4.5	0.7	3.3	10	78
CM 6740-7	3.6	4.1	0.8	2.4	9	83
M Per 183	3.7	3.2	0.6	3.1	11	83
Flour type 2						
HMC-1	3.9	2.7	0.7	2.5	9	85
CM 6740-7	3.1	2.6	0.7	2.2	10	85
M Per 183	2.3	2.2	0.9	2.7	10	86
Maize pearl starch[a]	0.6	0.3	0.7	0.1	12	87

a. Sample provided by Cartón de Colombia.

The ultra-refined cassava flours were obtained by classifying wholemeal flour, using meshes with 100-μm openings. In this study, two types of ultra-refined flours were handled: type 1, which came from either the total disintegration or grating of roots before drying in a continuous artificial system; and type 2, which was obtained by milling chips that were dehydrated in a batch or fixed-bed dryer.

This study also compared the rheological patterns of maize pearl starch with those of the ultra-refined flours of the three cassava varieties that were finally selected. The patterns for refined cassava flours were significantly different to those of the native starches of these same three cassava varieties.

The refined flour samples, without taking into account variety, presented a slight increase in viscosity during cooling, in contrast to the native or pure cassava starches, thus showing higher product stability

Table 23-10. Characteristics ascertained by amylographs[a] of native starches extracted from previously selected cassava varieties.

Variety	Tgel (°C)	Vmax (BU)	V 90 (BU)	V 90/20 (BU)	V 50 (BU)	tcook (min)	Gel instability (BU)	Gel index (BU)
HMC-1	25	507	420	280	380	13	227	40
CM 6740-7	26	420	400	241	380	15	179	20
M Per 183	25	420	400	250	320	13	170	80
CM 523-7	23	410	340	218	350	11.5	192	20
M Col 1522	20	500	420	260	345	15	240	75

a. Abbreviations Tgel refers to gelatinization temperature; Vmax, maximum viscosity; V 90, viscosity at 90 °C; V 90/20, viscosity at 90 °C after 20 minutes; V 50, viscosity at 50 °C; tcook, cooking time; Gel index, gelation index.

over time. Stability is higher in maize pearl starch (possibly a modified starch but information not supplied by the company). When the varieties were compared for viscosity (Table 23-12), the performance found to most resemble that of pearl starch was that of variety HMC-1 for both types 1 and 2 of ultra-refined flour. Gelatinization temperatures were between 65 and 82 °C, and maximum peak viscosity was between 100 and 120 BU.

Gelatinization temperature is a very important factor in starch used as raw material for glues. It varies with different starches, and is indispensable for applying the enzyme, enabling it to act effectively in starch hydrolysis. Furthermore, the lower the gelatinization temperature, the less energy is consumed in manufacturing glues.

The viscosity curve of maize pearl starch showed great stability over time to temperature changes and also resistance to shearing stress over time. Similar characteristics also appeared in samples of ultra-refined flour (types 1 and 2) from variety HMC-1. Stability is important in most products containing starch, as it helps their conservation and good appearance.

Adjusting two selected formulas for glues

Initially, to select the glue formulas for this study, several adjustment tests were carried out, taking into account solid contents, additives in the formula, effects of different reagents used, temperature, and agitation times. The first formulation for glue, using enzymes, was as follows:

Refined cassava flour	25%
Water	75%
Calcium chloride	0.1%
alpha-amylose	0.027% (temperature between 70 and 80 °C)
Hydrochloric acid	0.47%
Anti-foam	0.47%
Sodium hydroxide	0.70%
Talcum	5.88%
Formol	4.7%

The second formula, using chemicals, involved the application of magnetic and manual agitation in the laboratory. This conditioned the cassava flour with 10% solids. Borax may be added to stop the sodium hydroxide reaction, and the anti-foam prevents froth from forming through agitation. The formula for this glue was as follows:

Refined cassava flour	10%
Water	90%
Anti-foam	1.5%
Sodium hydroxide	1.5%

A general conclusion of this part of the study was that the ultra-refined flours (with <100-μm-diameter particles) from the three cassava varieties selected were suitable as raw materials for glue manufacture, using either the chemical or enzymatic method. The glues obtained were suitable for sealing cardboard boxes and had characteristics that complied with the requirements set by the standard sample.

With the enzymatic formula, glues achieved short fixing times because of the high solid contents, which

Table 23-12. Data from amylographs[a] of ultra-refined flours from three selected cassava varieties and maize pearl starch.

Identification	Tgel (°C)	Vmax (BU)	V 90 (BU)	V 90/20 (BU)	V 50 (BU)	tcook (min)	Gel instability (BU)	Gel. index (BU)
Flour type 1								
HMC-1	82	100	90	95	100	9	5	5
CM 6740-7	80.5	95	60	90	100	11	5	10
M Per 183	67	140	140	110	140	15	30	30
Flour type 2								
HMC-1	65.5	120	120	100	120	27	20	20
CM 6740-7	58	160	160	160	180	15	0	20
M Per 183	70	200	175	145	210	16	55	65
Maize pearl starch[b]	79	120	110	125	120	11	5	-5

a. Abbreviations Tgel refers to gelatinization temperature; Vmax, maximum viscosity; V 90, viscosity at 90 °C; V 90/20, viscosity at 90 °C after 20 minutes; V 50, viscosity at 50 °C; tcook, cooking time; Gel index, gelation index.

b. Sample provided by Cartón de Colombia.

generated certain advantages. These glues could therefore be used for boxes with a heavy carrying capacity (10–20 kg). In contrast, the chemical formula, involving low solid contents, created a glue with longer fixing times (1 hour) and which was more suitable for boxes with a light carrying capacity (7 kg) and not requiring immediate shipping.

Table 23-13 summarizes the principal characteristics of the two formulas (enzymatic and chemical), and compares them with the standard glue, that is, glue 002 made by Almidones Nacionales. Table 23-14 records the relative sale prices of several glues found on the market and used in the industry to seal cardboard boxes, and compares them with the glues made from refined cassava flour. The value of the enzymatic glue was US$0.06 per kilogram. The estimated sale price of glues in this phase of the project showed that incorporating cassava flour in the formula was advantageous.

Additional activities were carried out informally to strengthen the potential of cassava flour for use in the glue industry, and consider related possible research topics. However, a glue manufacturer evaluated the glues and found that, overall, apparent stability was good and the glue was moderately dark in color. Fixing tests were carried out for paper on paper, kraft paper on kraft paper, and kraft paper on cardboard and on glass. Results showed excellent adhesion. A glue with such characteristics could be used to manufacture kraft paper bags and seal cardboard boxes.

In addition to manufacturing glues for sealing cardboard boxes, the possibility of entering the agglomerate wood market (plywoods), replacing wheat flour, was proposed. In this industrial application, glues must unite two faces of timber to form an agglomerate.

Table 23-14. Relative sale prices compared for different glues used to seal cardboard boxes, Colombia, May 2002.

Glue	Sale price (US$[a]/kg)
Enzymatic formula (CLAYUCA)	0.06
Chemical formula (CLAYUCA)	0.02
Polyvinyl acetate (PVA)	0.28
Hot-melt adhesive (HMA)	0.69
Pegol 015[b]	0.09

a. US$1.00 = Col$1800 in 2010.
b. Supplied by Industrias del Maíz S.A.

Traditionally, the glue was based on phenol formaldehyde, a formulation that involves a high percentage of wheat flour to help adhesion by increasing the quantity of solids in the formula.

Laboratory tests showed that 50% of wheat flour could be replaced by cassava flour. A 100% substitution was not possible as cassava flour reduces viscosity by 20%, compared with wheat flour. Nevertheless, cassava flour is a new alternative for reducing the costs of glue in the manufacture of plywoods. At the time of writing, cassava flour cost US$0.31 per kilogram, while wheat flour cost US$0.56 per kilogram.

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Table 23-13. Characteristics of glues made from refined cassava flour compared with those of a standard glue (glue 002, Almidones Nacionales, Colombia).

Variable	Enzymatic glue	Chemical glue	Standard[a] glue
Solid contents (%)	25%	10%	23%
Viscosity (cP)	8000–12000	10000–18000	6000–12000
pH	7–9	10	8–9
Adhesion	Good	Good	Good
(% of scraped area)	(100 s)	(3600 s)	(100 s)
Adhesive tack	Excellent	Good	Excellent
Stability (days)	30 days	15 days	30 days

a. Glue 002, made by Almidones Nacionales S.A., Yumbo, Colombia.

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Cassava Leaf Flour for Human Consumption

Johanna A. Aristizábal and Andrés Giraldo

Introduction

Leaves of cassava (*Manihot esculenta* Crantz) contain, on a wet basis, 77% water, 8.2% crude protein, 13.3% soluble carbohydrates, 1.2% fat, and 2.2% crude fiber. Cassava leaves are regarded as a green vegetable with a high protein concentration. They also contain minerals such as iron, calcium, potassium, phosphorus, magnesium, copper, and zinc, which are significant in human nutrition. Cassava leaves also have high contents of vitamins, particularly beta-carotenes and vitamins A, B1, B2, B6, B12, and C; and of other vitamins, including niacin, which is a depurative and powerful detoxicant; folic acid, which is a powerful anti-anemic vitamin; and pantothenic acid, which prevents deterioration in skin tissues (Guillén 2004).

Table 23-15 shows that beef surpasses cassava leaves for protein content. However, for many other nutrients such as calcium and certain vitamins, cassava leaves surpass both beef and cow's milk by large margins.

Table 23-15. Nutritional value of cassava leaves, beef, and cow's milk in accordance for a person's Daily Reference Values (DRV).

Nutrient	DRVs	Cassava leaves (100 g)	Beef (100 g)	Cow's milk (100 g)
Calories (%)	2000 cal	4.0	7.0	3.0
Protein (%)	50.0 g	13.0	41.0	6.0
Iron (mg)	18.0 mg	42.0	18.0	0.6
Calcium (mg)	1000.0 mg	67.0	3.0	25.0
Niacin (mg)	20.0 mg	17.0	36.0	1.0
Vitamin A (mg)	750.0 mg	261.0	0.5	5.0
Vitamin B (mg)	10.9 mg	28.0	10.0	4.0
Vitamin C (mg)	60.0 mg	1036.0	0.0	0.0

The nutritional composition of cassava foliage varies in quality and quantity, according to cultivar, time of cutting, planting density, and the proportion of leaves (leaf blades + petioles) and stems. The part of the plant used also determines nutritional composition, for example, if only leaf blades are used, protein content would be 23% to 28% (dry basis). But, if petioles and apical green branches are also included, protein content would be reduced to 18% to 21%. An inverse relationship occurs for fiber content, which tends to be about 9% for leaf blades, but increases to 20% to 25% when the entire upper part of the plant is incorporated (Domínguez [1983]). Some authors therefore consider that cassava leaves to have high potential as animal feed and human food. Petioles and, consequently, leaves, from the nutritional viewpoint, are valuable.

Most research on the use of cassava leaves for human consumption has been conducted in Brazil. Much of the research evaluated this product incorporated into dietary mixtures that were consumed by people with nutritional deficiencies or with health problems because of low levels of vitamins and minerals (Brandão and Brandão 1991).

Although the principal disadvantage of cassava leaves is their HCN content, these levels can be reduced by efficient flour preparation. In countries such as Indonesia and Tanzania, cassava leaves are consumed fresh, like any other vegetable, after first cooking. In Peru, cassava leaves are consumed in capsules or tablets as nutritional supplements.

The use of cassava leaf flour for human consumption is not promoted or commercially supported in the way it should be. Not only could it be as a dietary alternative, providing nutritional benefits, but it could also, as a byproduct, be an option for adding aggregate value to the cassava crop. The inclusion of cassava leaf flour for human consumption is a food alternative. Hence, methods and processes for producing high-quality flour should be established for its use as a raw material in the preparation of foodstuffs such as soups, pies, and extruded products. Giraldo and Aristizábal (2006) therefore studied the process of obtaining cassava leaf flour for human consumption. They proposed alternative uses according to end-product quality and determined the technical and economic indicators for the flour's production.

Preparing flour from cassava leaves

In preparing cassava leaf flour, the various stages of operation were evaluated for the most suitable conditions for obtaining a quality product. Similarly, evaluations and analyses were conducted to calculate how to eliminate HCN during flour production.

Selecting varieties. Cassava varieties HMC-1 and M Col 1505 were selected on the following criteria:

- *Availability*, whereby typical cassava varieties planted near CIAT were chosen, and
- *Variety.* To guarantee low HCN contents in the end product, sweet varieties with HCN contents of about 180 ppm and planted in inter-Andean valleys were chosen.

Harvesting, selecting, and adapting the raw material. Two harvests of cassava leaves were carried out, one at 3 months and the other at 5 months, to compare the composition (e.g., protein, fiber, and HCN) of cassava leaves at harvest. Harvest was carried out by cutting the plant at a height of 30 to 40 cm above ground level to guarantee that the plant would re-sprout for a future harvest.

The harvested plants comprised leaves (i.e., leaf blades and petioles) and stems. However, only leaf blades were needed for the process. During selection, only those leaves that presented the characteristic green color of the cassava leaf were taken. Those leaves that had yellow or coffee-colored leaf blades, or showed spots were rejected. In preparing the raw material, both stems and petioles were removed manually, so to obtain only leaf blades.

Washing and disinfection. Cleaning ensured that the end product presented adequate microbiological and commercially acceptable characteristics according to Colombian Technical Standard NTC no. 267. This standard is used to obtain flour suitable for human consumption. Adequate washing reduced the microbial population present in the raw material, thus obtaining an aseptic product.

To wash, drinking water in a container was used. The leaves were submerged for 15 min, thus removing impurities such as earth, insects, and larvae, and residues of insecticides or pesticides. The leaves were then removed from the water and disinfected with an aqueous solution of sodium hypochlorite at a concentration of 20 ppm. The leaves remained in the solution for 10 min, the maximum time possible before leaf color was affected. The equipment had also been previously washed and disinfected with a hypochlorite solution at 50 ppm.

Reducing leaf size. Leaf blades were obtained in their entirety, which meant that they had to be treated to help eliminate HCN contents. Leaf blades were therefore chopped into smaller pieces, using an industrial mill that possessed appropriate cutting blades. The chopping broke up the leaf tissues, releasing HCN, and thus ensuring that HCN levels in the end product were lower than in the initial raw material. Different types of cuts were evaluated; the more finely the leaf blades were cut, the more efficient was the release of HCN.

Drying. Drying was carried out in two ways—solar and artificial drying (in a tray dryer)—to determine which was the better method. Solar drying was carried out on inclined trays, placing an average of 2 kg of leaf blades per tray. The blades remained exposed to the sun for 24 hours or more, depending on climatic conditions. Solar drying was considered to be inefficient and, microbiologically, the product could not be guaranteed to be aseptic. Artificial drying was carried out in a tray dryer with air circulation, using temperatures of 40, 50, and 60 °C.

After leaf blades were dried by the two methods, samples were collected from each test for HCN analysis to determine the temperature at which the enzyme linamarase acted most efficiently on cyanogenic glucosides (linamarin and lotaustralin) to release HCN.

To determine HCN contents, a protocol was established that included NaCl and activated carbon during extraction to ensure that the spectrophotometer readings were clear, as leaf chlorophyll colors samples. Results indicated that artificial drying at 60 °C eliminates most of the HCN (Figure 23-14).

Milling. The dried leaf blades were milled into small pieces, comparing three types of mills: blade mill, hammer mill, and mill sieve. For each, efficiency was evaluated according to the amount of flour and granulometry obtained.

Granulometry of cassava leaf flour was determined, using sieves of different mesh numbers: 50 (300-μm openings), 70 (212 μm), 100 (150 μm), 140 (106 μm), 270 (53 μm), and bottom. The best granulometry was obtained with the mill sieve, for which almost 95% of flour passed through the no. 70 mesh (212 μm).

Analyzing cassava leaf flours

Once cassava leaf flour was obtained, tests were carried out to evaluate the digestibility of protein, dry matter, and fiber in diets. That is, for the tests, diets were prepared, based on cassava leaf flour. For comparative purposes, the control diet was based on casein, a protein that has an almost 89% absorption rate in the human organism.

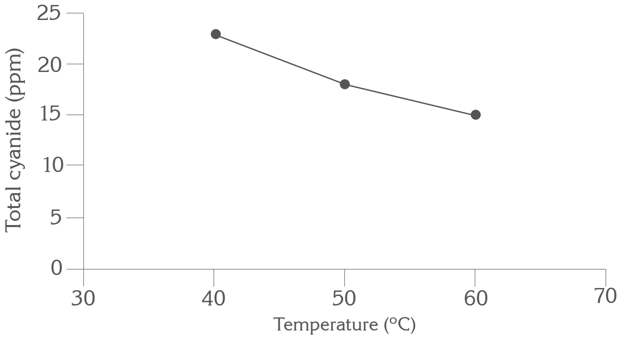

Figure 23-14. Final total cyanide of dried cassava leaves at three drying temperatures.

All the diets were formulated as isoproteic and isoenergetic. The control diet was prepared with 12% protein (casein), 10% sugar, 6% oil, 60% maize starch, 6% fibers, and 6% of a premixture of vitamins and minerals. For the diets with cassava leaves, the casein was replaced with cassava leaf flour at the established percentages of 10% and 20%.

Tests were carried out with laboratory mice that were distributed at random in metabolic cages that were designed especially to provide food to the animals and collect their excreta. The animals were fed the diets over an experimental period of 15 days. For the first 7 days, the mice were habituated to the diets. Over the next 8 days, samples were collected.

During the experiment, three treatments were evaluated: 10% cassava leaf flour, 20% cassava leaf flour, and the control, each having three replications. The three diets were analyzed for contents of dry matter, protein, neutral detergent fiber, and ash; and for energy. The excreta were tested for digestibility of dry matter, protein, and neutral detergent fiber; and for energy.

Habituation was necessary to ensure that the animals' digestive tracts were cleaned out and accustomed to the treatment or diet that would be fed to them. During habituation, the animals received the food but neither the residues nor the excreta were weighed. From the eighth day onwards, excreta from each mouse were taken, and the quantities of food provided and the amount left by each mouse were calculated.

The excreta, collected after habituation, were sampled and cleaned to remove hairs and food particles. They were then weighed and the data recorded. The excreta were kept in a freezer, in bottles that were duly marked with the corresponding mouse's number and diet. After the samples were collected, each bottle of excreta was lyophilized to obtain dry and solid samples for analyses on the digestibility of each diet supplied to the mice.

Data on the digestibility of dry matter and protein (Figure 23-15) suggested that the diet with 10% leaf flour is the most suitable for incorporation into a product for human consumption. The level of digestibility could be improved by mixing the leaves with food rich in methionine, which, in this case, is the limiting amino acid (Lancaster and Brooks 1983).

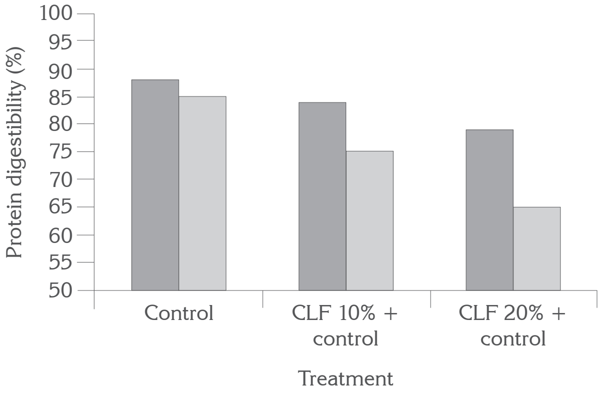

Figure 23-15. Dry matter (■) and protein (□) digestibility of diets evaluated in mice (CLF n% refers to cassava leaf flour at the percentage of substitution).

Conclusions

Any cassava variety, either sweet or bitter, can be used to obtain cassava leaf flour because the stages of chopping and drying guarantee an efficient elimination of HCN, the contents of which are low in the end product.

Efficient washing of leaves and their later immersion in sodium hypochlorite solution, together with a prior washing and disinfection of equipment used in the process, will ensure that the flour obtained from cassava leaves is of acceptable microbiological quality.

The release of HCN is favored by the leaves being finely chopped and exposed to long drying times at a temperature of 60 °C in a dryer with forced hot-air circulation.

From the nutritional viewpoint, the recommended rate of including cassava leaf flour is 10%, as being the most digestible.

To guarantee cassava leaf flour for human consumption that is competitive on the market, artificial drying systems must be used. Good manufacturing practices must also be implemented throughout production to minimize risks of contamination and ensure high levels of safety and quality for the end product.

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