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Cassava Flour and Starch:

Progress in Research and Development

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Centre de coopération internationale en recherche agronomique pour le développement
Département des systèmes agroalimentaires et ruraux
CIRAD-SAR

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

The Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) is a French research organization that specializes in agriculture in the tropics and subtropics. It is a state-owned body and it was established in 1984 following the consolidation of French agricultural, veterinary, forestry, and food technology research organizations for the tropics and subtropics.

CIRAD's mission is to contribute to the economic development of these regions through research, experiments, training, and dissemination of scientific and technical information.

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CONTENTS

Page

SESSION 7: INTEGRATED PROJECTS

APPENDICES

FOREWORD

The 1994 International Meeting on Cassava Flour and Starch, held in Cali, Colombia, focused on cassava products and their use and potential development. More than 130 scientists, representing 29 countries, participated, presenting 45 papers and 80 posters, of which 41 papers are published in these proceedings.

The Meeting was co-chaired by CIRAD/SAR and CIAT, and was made possible by the sponsorship of the EU, IDRC, MAE, NRI, ORSTOM, UBA, UNESP, and UNIVALLE.

Lodging and facilities were provided by CIAT, and we thank Dr. W. Scowcroft, Director General of Research, and CIAT employees whose efficient help was invaluable to our presentations.

We also thank Dominique Dufour, of CIRAD/SAR and stationed at CIAT, who supervised the scientific preparation of the sessions, and whose dynamism was instrumental for the overall organization of the event. Also much appreciated was the smoothly efficient logistical support provided by Mrs. María Eugenia Cobo.

Not only the efficient organization, but also the number of participants, their diversity, the quality of their presentations, and their willing participation, contributed to the value of the discussions, making this Meeting a significant scientific event.

CIRAD/SAR and CIAT, as co-publishers of these proceedings, were assisted by CIAT's Communications Unit. Despite careful editing and production, errors may remain, for which we take full responsibility.

The organizers

PREFACE

Until recently, most efforts in tropical agriculture were focused on increasing cereal productivity, thus neglecting root and tuber crops such as cassava, long considered as a "primitive crop," as "food for the poor," and as having "poor nutritional value." Cassava was rarely included in R&D programs for tropical agriculture.

But, with population increase and rapid urbanization in developing countries, cassava has become more important as a source of food security and dietary calories for the inhabitants of these countries. The unusual climatic variations witnessed in recent years, along with the prospect of global warming, highlight further advantages of this hardy, drought-resistant crop. Policy makers have therefore become more aware of the crop's significance and are encouraging its research.

The root's remarkable capacity to adapt to various agroecological conditions and its potential for high starch yields first oriented research toward increasing productivity through varietal improvement, new cultural practices, and crop protection.

Only since 1985—which is remarkable, considering this edible root was domesticated more than 5,000 years ago—have studies in food demand begun to emphasize the improvement of postharvest handling, processing, and marketing of cassava and its derived products. Biotechnology research and opportunities are now also taken into account in R&D programs on products, byproducts, and even the wastes produced by processing plants.

The 1994 International Meeting on Cassava Flour and Starch, organized in Cali, Colombia, demonstrated this burgeoning scientific interest in cassava processing and its role in the socioeconomic growth of developing countries. Producers, researchers, processors, and consumers of cassava products have never before met in such significant numbers to share their experiences, present their work and results, and exchange information. The technological development of cassava processing and conservation will surely improve as participants return to their work and apply their new knowledge.

The themes presented during the Meeting were:

- The existing and potential uses of cassava in the world.

- The physical and chemical composition and functional properties of cassava flours and starches.
- The possibilities of bioconversion of processed products and byproducts.
- Technological improvement of cottage and industrial processes.
- Development of new products.
- Integrated development of cassava products to supply market needs.

These themes set the scene for many stimulating discussions. The necessarily multidisciplinary scientific approach, together with the participatory research approach—both involving the various components of the cassava production, processing, and marketing system—emerged as a "recurrent pattern" for quality work. Currently, these approaches form the only way to contribute significantly to the socioeconomic growth of developing countries.

The papers reported the most recent results of current research programs. They also pointed toward future research directions and suggested ways of translating results into socioeconomic benefits for all groups involved in cassava.

With the publication of these proceedings, both those who could and those who could not attend the Meeting will be able to reap from the wealth of knowledge presented in these papers, and so develop new methodologies and new products and technology for their production, and, most importantly, better guide the direction of thinking and planning for their communities' development.

Dany Griffon
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CIRAD/SAR

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Leader, Cassava Program
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Session 1:

Introduction

CHAPTER 1

ADDING VALUE TO PRODUCTS, BYPRODUCTS, AND WASTE PRODUCTS OF SMALL AND MEDIUM-SCALE CASSAVA-PROCESSING INDUSTRIES[1]

*Dany Griffon**

Introduction

The tropical root crop cassava (*Manihot esculenta* Crantz) is considered a "low risk" crop that adapts readily to a wide variety of agroecological conditions. It is highly efficient in the conversion of solar energy to starch.

Cassava serves as a subsistence crop for marginal rural populations in the tropics, because it efficiently uses the mineral reserves of infertile soils; it can withstand climatic variations; it can stay in the ground unharvested for long periods; it resists drought; and it can function as a food-security crop in times of famine and other disasters.

Cassava's importance in the socioeconomic development of rural areas has gained recognition during the last 20 years. Historically, its role in Latin America, where the crop originated, was that of a basic foodstuff for rural inhabitants. Now it is also a source of income and employment for rural populations.

As urbanization increases in Latin America, governments are becoming interested in markets for cassava-derived products. National and international research projects on cassava and its products have been set up, attracting new funding for their expansion.

The Need for Technological Research

Originally focused on improved yields, cultivation practices, and crop protection, cassava research has, since 1985, also focused on processing, quality, and new product development. In 1988, a 3-year European Union (EU) project, "Quality improvement of cassava-based fermented products," involving French, African, and Latin American research institutions, was set up. This project built up knowledge and strengthened exchange between teams investigating cassava conservation and processing technologies. Traditional fermented products such as "gari" in Togo, "chickwangue" in the Congo, and "sour starch" in Colombia were chosen for the project.

A follow-up project was proposed to the EU in 1992 as a result of interest generated by the first project, especially in sour starch in Latin America; the need to identify new uses

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1. No abstract was provided by the author.

for cassava, and improve market knowledge; the need to involve small and medium-scale processing plants in minimizing their environmental impact by treating liquid and solid wastes; and the dynamism, motivation, and experience of the research groups assigned to the work.

A Multidisciplinary Project

Under the EU program "Science and technology of the living for development," the EU commission approved a contribution of 760,000 ECUs for a 3-year project entitled "Value enhancement of products, byproducts, and waste products of small and medium-scale cassava-processing industries in Latin America."

Value enhancement involves increasing the value added during processing; designing, developing, and marketing quality products; and reducing environmental pollution caused by processing.

The project aims to help small- and medium-scale cassava producers and processors strengthen their positions in existing markets and penetrate new markets. Researchers would study markets for cassava and its derived products; match cassava varieties with the specific technical requirements of users; improve the physicochemical, functional, and nutritional properties of cassava flours, starches, and other products; develop new second-generation products, and carry out feasibility evaluations; and identify locally feasible technologies for treating waste products.

The project has adopted a multidisciplinary—agronomy, economics, and biotechnology—and interinstitutional approach to achieve optimal impact. The project brings together ORSTOM (France and Colombia), NRI (United Kingdom), CIAT (Colombia), UNIVALLE (Colombia), the University of Buenos Aires (Argentina), UNESP (Brazil), and CIRAD (France, Colombia, and Brazil), whose Rural and Food Processing Systems Department is in charge of general coordination.[2] The 3-year project was approved in November 1992, and funding began in March 1993.

Scientific Organization

The project is structured around five complementary research operations, each coordinated by a scientist:

Operation 1 characterizes raw materials and evaluates the quality of cassava flours and starches for processing. (Managed by NRI and coordinated by Dr. June Rickard.)

Operation 2 studies the treatment of liquid and solid waste products from processing. (Managed by ORSTOM and coordinated by Dr. Didier Alazard.)

Operation 3 studies the bioconversion of flours and starches for the development of new products for use in the food industry. (Managed by ORSTOM and coordinated by Dr. Maurice Raimbault.)

Operation 4 focuses on improving the functional properties of cassava flours and starches, and studies the physicochemical and biochemical properties necessary for elaborating new products. Some of the new products being studied are modified starches, cyclodextrins, glucose and maltose syrups, extruded products,

2. For explanation of acronyms, see "List of Acronyms and Abbreviations Used in Text," p. 402.

and fat analogs. (Managed by CIRAD/SAR and coordinated by Dr. Gerard Chuzel.)

Operation 5 studies the traditional markets for cassava and potential markets for newly derived cassava products. (Managed by CIAT and coordinated by Dr. Guy Henry.)

The wide range of cassava clones in the global germplasm collection held at CIAT is vital to the project.

The UNIVALLE team in Colombia and the UNESP team in Brazil are involved in the research operations mentioned above, and in forming links between processors and product users. The University of Buenos Aires in Argentina studies the bioconversion of flours and starches.

Accountable to the EU, CIRAD/SAR is responsible for the overall scientific and financial coordination. (Managed by Dr. D. Griffon with Dr. Nadine Zakhia. In Latin America, coordinators are Dr. D. Dufour in Cali, Colombia, and Dr. G. Chuzel in São Paulo, Brazil.)

Conclusions

The work plan, research teams, and financing became operative in 1993. The first results of the research are presented in these proceedings, showing that added value is indispensable in the generation of income and employment. To obtain it, the following activities must be carried out: varietal improvement to satisfy technological applications; improvement in raw material conservation and processing; innovation and diversification of final products; attention to product quality; and marketing of the final products.

Cassava producers, processors, and traders can benefit from the scientific and technical knowledge generated by this project, thus obtaining a better market response toward this long-neglected tropical starchy food.

Chapter 2

CORAF Networks[1]

G. Hainnaux*

What Is CORAF?

The Conférence des responsables de recherche agronomique en Afrique de l'Ouest et du Centre (CORAF) is a tool for cooperation in agronomic research. It provides a framework for collective action and for the exchange of information and experience. CORAF aims to:

(1) Promote cooperation, collective action, and information exchange among member institutions;
(2) Define common research objectives;
(3) Prepare common research projects;
(4) Create, operate, and develop associate networks and regional research workers' teams; and
(5) Collaborate with international agronomic research centers, regional or international organizations, and funding agencies.

The institutional and operative organs of CORAF are the plenary conference, follow-up committee, executive secretariat, and associate networks.

CORAF is run by a 10-man follow-up committee, six who represent African national programs and four who are associate members from European countries. This committee elects, from among its members, a president and a vice president to represent CORAF. They are assisted by the executive secretariat.

Associate Networks

An associate research network is a group of researchers who work together on a research theme recognized as priority by CORAF. The network aims to:

(1) Strengthen existing agronomic research systems and give them regional and international dimension;
(2) Promote the acquisition of scientific knowledge and optimal use of results;
(3) Encourage joint action with International Agricultural Research Centers (IARCs) and with other international and regional organizations;
(4) Prepare projects and submit them to external funding agencies;
(5) Encourage evaluation of research in various agroecological and socioeconomic conditions; and
(6) Facilitate the setting up of interdisciplinary teams, and the training of researchers.

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1. No abstract was provided by the author.

At present, six associate networks belong to CORAF, doing research on groundnuts, cotton, maize, cassava, rice, and resistance to drought. The CORAF networks take into account the bilateral and multilateral relationships of member institutions.

Organization and operation of associate networks

An associate network has a general assembly, and a steering committee. The general assembly is composed of the coordinator, national correspondents, and one to several associate correspondents. The steering committee comprises the coordinator, correspondents, three members nominated by the general assembly, two scientific authorities outside the network and nominated by the general assembly, and donor representatives. The steering committee assists the coordinator in managing the network and in following up its scientific activities.

The general assembly's mission is to establish scientific priorities and research orientations. It liaises with scientific partners and with other networks, and convenes once every 3 years.

Research projects

The scientific activities of a given network are divided into major themes that emerge according to national program needs. These themes are implemented as projects, which take into account:

(1) The scientific priorities within each theme, identified by the network's general assembly;
(2) The potential of each of the network's partners; and
(3) Acquired experience and existing work.

The network appoints an authority to lead each project and specifies the scientific objectives, duration, partners, and resources to be acquired. The network's steering committee determines the timing and methodology for the internal scientific evaluation of the work.

Base Centers

A base center is an agronomic research center that belongs to a national network and is open to regional and international cooperation within the framework of a network. It brings together sufficient human, financial, and material resources to attain scientific objectives and achieve results that are applicable or adaptable to other countries having the same development preoccupations.

Operation

A base center is placed under the aegis of an international network and of the national network that shelters it. It:

(1) Provides the networks with supplementary means for reinforcing a national program (scientific personnel, equipment, operations);
(2) Contributes to regional cooperation by improving the working relationships among research workers of the same region (visits, workshops, seminars);
(3) Participates in the training and retraining of scientific and technical personnel of countries of the region;
(4) Provides expertise to third parties in the form of support or consultation; and
(5) Promotes the diffusion of information and publication of scientific and technical documents.

Activities

Base center programs are planned with the following factors taken into account: national agricultural policies; development needs of each country; national research programs; priorities defined by the respective network; scientific capabilities of members of the respective network; and other regional and international arrangements in member countries or outside. These programs aim to:

(1) Improve crops and livestock according to socioeconomic, agronomic, biological, and edaphoclimatic conditions;
(2) Develop living collections to make possible the sharing of available genetic resources among member institutions; and
(3) Establish databases and encourage joint studies of common interest.

The Cassava Network: An Example of an Associate Network

Members

Network members number 156 researchers from agricultural research institutes of CORAF member (or associate member) countries, that is, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, the Congo, Côte d'Ivoire, France, Gabon, Guinea, Madagascar, Mali, Niger, Senegal, and Togo.

Associate network members are researchers from agricultural research institutes of countries who do not belong to CORAF: Belgium, Colombia, Italy, Rwanda, Spain, United Kingdom, USA, Germany, and Zaire.

Other organizations connected with the Network are the International Institute of Tropical Agriculture (IITA), based in Ibadan, Nigeria; the International Board for Soil Research and Management (IBSRAM), based in Bangkok, Thailand; and the International Plant Genetic Resources Institute (IPGRI), based in Rome, Italy.

Major research priorities

The Network has three main areas of priorities:

(1) Make an inventory of, characterize, and evaluate germplasm for selection;
(2) Develop technologies for promoting longer shelf life, postharvest handling, and improving nutritional quality; and
(3) Study the management of cassava-based systems to improve system productivity and conditions for propagation.

Major collaborative projects

CORAF has begun establishing thematic base centers in the Congo and Togo. Four projects are under way:

(1) "Setting up and monitoring a multisite agronomic evaluation of cassava in Africa." Located in Togo, it has researchers from the Congo, Côte d'Ivoire, France, and Togo.
(2) "Improving African cassava cultivars." Located in the Congo, the researchers come from the Congo, Côte d'Ivoire, France, Italy, and Spain.
(3) "Improving detoxification methods." Also located in the Congo, the researchers are from the Congo, France, and Togo.
(4) "Improving foodstuffs processed from fermented cassava." Again located in the Congo, the researchers are from Belgium, Colombia, the Congo, France, Mexico, and Togo.[2]

2. For more information about the Cassava Network, contact the Coordinator, Dr. Joseph Mabanza, DGRST-ORSTOM, BP 181, Brazzaville, Congo; tel.: (242) 81 26 80 or 81 26 81; telex: 5404 (Attn. ORSTOM); fax: (242) 83 22 05.

Summary of projects and activities carried out by the Cassava Network

Project	Activity	Country
(1) Improvement of production, processing, and nutritional transformation and quality of cassava in Central and West Africa	(a) Create a base center to improve cassava varieties and cropping systems	Cameroon, the Congo, Gabon, Zaire
	(b) Search and evaluate local cultivars; set up a multisite trial network to assess the genotype-by-environment interaction	Central Africa, Cameroon, the Congo, Gabon, Guinea, Benin
	(c) Improve cassava processing and conservation practices; improve nutritional quality of products and byproducts	Network member countries: France, Germany, Spain
(2) Cassava agronomy in West Africa	(a) Create a thematic base center on the improvement of cassava agronomy	Benin, Côte d'Ivoire, France, Germany, Ghana, Guinea, Senegal, Sierra Leone, Togo
	(b) Improve management of soil fertility in cassava-based farming systems	Same countries as above
	(c) Implement biological control of cassava pests	Countries of the networks

CHAPTER 3

THE CASSAVA BIOTECHNOLOGY NETWORK AND BIOTECHNOLOGIES FOR IMPROVING THE PROCESSING QUALITY OF CASSAVA[1]

*A. M. Thro**, *W. M. Roca***, and *G. Henry****

Introduction

Cassava plays two roles in tropical agriculture: it provides food security for many countries; and is a source of raw material for agroindustrial development. Because cassava is a highly reliable crop, even on relatively poor soils, it can play these roles in areas otherwise poor in resources.

The Cassava Biotechnology Network (CBN) is one response by CIAT to cassava's incognito outside the tropics. By 1984, powerful new biotechnological tools for agricultural research were developing rapidly but chiefly in countries where cassava was not grown. Thus, little was being done to apply these new tools to cassava even though biotechnology could significantly enhance cassava as a traditional staple and help develop new end uses for diverse markets.

The CBN was founded in 1988 to provide a forum for cassava biotechnology issues and to foster cassava biotechnology research on priority subjects (CIAT, 1989). Since then, many cassava biotechnology research projects have been organized and funded (Table 1).

CBN Objectives

(1) Identify priorities for cassava biotechnology research.
(2) Stimulate complementary, collaborative biotechnology research on topics of established priority through (3).
(3) Foster free exchange of information on cassava biotechnology research, including techniques, results, and materials.

Defining Biotechnology

Among the many definitions of biotechnology is that formulated at the International Meeting on Cassava Flour and Starch (held 11-15 January, 1994, at CIAT, Cali, Colombia):

> "the deliberate use of an organism, or part of an organism, to make or modify products or to improve plants or animals."

Biotechnologies in the context of cassava processing include both genetic manipulation and the use of microorganisms to effect desired changes.

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1. No abstract was provided by the authors.

Table 1. Cassava biotechnology research projects, partial listing, 1994.

Research area	Number of projects	Countries and international centers[a]
Tissue culture, micropropagation	Many	Barbados, Brazil, Cameroon, Cuba, China, Indonesia, Nigeria, Panama, Peru, Samoa, Venezuela, Zaire, and others CIAT, IITA
Regeneration	9	China, France, the Netherlands, UK, USA, Zimbabwe CIAT, IITA
Transformation	7	Brazil, Canada, UK, USA CIAT, IITA
Molecular mapping, markers, fingerprinting	6	France, UK, USA CIAT, IITA
Virus resistance	3	China, the Netherlands, USA, Zimbabwe
Cyanogenesis	7	Denmark, the Netherlands, Thailand, USA CIAT, IITA
Photosynthesis	2	Australia, USA
Cryopreservation	2	France CIAT
Processing	Many	Argentina, Brazil, Colombia, the Congo, France, Ghana, India, Nigeria, South Africa, Tanzania, UK, and others CIAT

a. IITA = International Institute of Tropical Agriculture, based in Ibadan, Nigeria.

CBN's Interest in Cassava Processing, Including Flour and Starch

CBN's interest in cassava processing, including flour and starch, traces back to the cassava demand studies CIAT conducted from 1984 to 1986 (CIAT, 1987). These were extensive studies of current and potential consumption of cassava, consumer preferences for cassava versus other staples, income generation and employment opportunities in cassava processing, and use of cassava in animal feeds. The possibilities for expanding the cassava market were also studied, including factors such as production costs, competing crops, and government policies.

The studies showed that cassava production potential exceeded cassava consumption; that cassava consumption, and so cassava production, were falling in Latin America; and that demand for cassava seemed to be present but the market was generally unable to bring cassava to the consumer, either in fresh or processed form. This meant that cassava's advantages—high yields of high-quality carbohydrate produced at low cost and even on poor soils—were not benefiting farmers nor urban consumers as they might. This translated into a high priority for research on cassava processing and products to increase markets for the crop and provide consumers with desirable products at low cost.

The CBN conducted its own priority assessments in 1988 (CIAT, 1989) and 1991. Its 1991 survey was of experts on the value of different possible applications of biotechnology to cassava (Henry, 1991). It revealed that, among possible biotechnological innovations for cassava, improving starch quality had a high, anticipated impact on small-scale farmers and on the market value of cassava (Table 2).

In late 1994, the CBN began a 5-year study to develop a versatile framework for using primary data for cassava research priority setting. This will refer especially to assessing the relative advantages of biotechnology as against other research approaches.

The CBN has also begun to establish its own direct contacts with the ultimate users of cassava research. In 1993, a CBN case study was conducted in northern Tanzania where the staple food is a stiff porridge of cassava flour. The flour is obtained by pounding dried-then-fermented cassava pieces. Villagers had specific quality preferences for the traditional product; some women had also experimented, but unsuccessfully, with mixing cassava and wheat flour to produce baked goods for sale in the small village restaurant (wheat flour was expensive and often scarce).

CBN teams were often asked for suggestions on improving the local methods of cassava processing, or on making a greater variety of products. This perspective, gathered directly from cassava users, suggests that a strong demand exists for research on the quality of cassava flour, even in areas with near-subsistence farming, where such demand might not be expected.

Current Research in Biotechnology with Reference to Cassava Quality and Processing

Genetic transformation of cassava

Genetic transformation, or genetic engineering, refers to inserting DNA of one genetic material into a cell of another genetic material; ensuring the DNA's successful incorporation into the cell's genome; and, if the DNA encodes one or more genes, subsequently expressing those genes in the phenotype of the cell. The most promising methods used to genetically transform cassava include physically bombarding cells with microprojectiles coated with DNA, and using the bacterial vector *Agrobacterium tumefaciens*.

Although single cassava cells have been transformed, they have yet to be regenerated as uniformly transformed plantlets. Regenerating from single callus cells or from protoplasts—

Table 2. Relative importance of cassava constraints and opportunities for which biotechnology may have a relative research advantage, by region and by anticipated impact of biotechnological innovations on small-scale farmers and market value of cassava.[a]

Biotechnology research topics	Importance by region			Impact of innovations	
	Africa	Latin America	Asia	Yield increase	Market advantage
Viral diseases	+++	+++	+	+++	+
Insect pests	+++	+++	+	+++	+
Cyanide toxicity	+++	+	++	0	++
Starch quality	++	++	+++	0	+++
Postharvest root deterioration	++	+++	+++	0	+++

a. +++ = high; ++ = medium; + = low; 0 = no change.

SOURCE: Roca et al., 1992.

already successfully used for genetic transformation in other species—has not been reported for cassava. In vitro regeneration of cassava plantlets has been achieved through somatic embryogenesis in a wide range of genotypes. These somatic embryos arise from multicellular buds and, when transformed, are chimeric.

Culture studies in embryogenic suspension are so far promising, and the possibility of other single-cell-based regeneration systems should be investigated.

Mapping the cassava genome

A framework genetic map of cassava, based on molecular markers, is now under construction through collaborative interchange agreements between CIAT and the U.S. Universities of Georgia and Washington—St. Louis. Several types of molecular markers are being used in the initial mapping work, including RFLPs from both total genomic DNA and cDNA, and RAPD primers.[2]

A molecular map of markers linked to traits of interest has the advantages that molecular markers are found in all genotypes, they are numerous (from hundreds to thousands in species so far investigated), and they are phenotypically neutral. This means that any normal plant will express many of them. A further advantage, and perhaps the most valuable to plant breeders, is that molecular markers are independent of external environment or the organism's developmental stage. As a result, molecular markers, and any traits linked with them, can be scored and selected in any environment and at any developmental stage, even using DNA from seedlings.

If, for example, molecular markers were established for a certain desired cooking quality of cassava, then a breeding population could be screened for that cooking quality even at the seedling stage, and even if the physicochemical basis of the desired cooking quality was unknown.

Cassava genomic and cDNA libraries have been produced. A mapping progeny has been developed from the cross Nigeria 2 X ICA Cebucan, whose parents were selected according to their variation for both agriculturally interesting traits and molecular markers. The first group of useful polymorphic markers has been identified. When completed, the framework map and the mapping population will be made available to cassava breeders and other researchers.

Genes for starch quality in cassava

Several research groups, for example, in Brazil, the Netherlands, and CIAT, are interested in working on transgenic approaches to cassava starch quality and quantity. To produce transgenic cassava with appropriate characteristics, researchers need to control the proportions of amylose to amylopectin so to permit new or wider uses of cassava starch. One form of control is through genes.

A private research group at Wageningen University, the Netherlands, used their work with potatoes to clone the starch biosynthetic genes of cassava: granule-bound starch synthase (GBSS, responsible for amylose synthesis), and branching enzyme (BE, responsible for the cross linkages that form amylopectin). This group is also working on regenerating and

2. For explanation of acronyms, see "List of Acronyms and Abbreviations Used in Text," p. 402.

genetically transforming cassava and is positioned to test the starch genes in cassava as soon as a transformation protocol is developed. Because the research is privately supported, the genes may not become available for public use, except in the long term.

CIAT (whose research results become publicly available) may be very close to having a transformation protocol for cassava, which, if confirmed, will then be optimized. CIAT is also investigating the priority applications that are the ultimate objective of developing the technology. In accordance with cassava research priorities, CIAT is working with published sequences of the BE, using polymerase chain reaction (PCR) technology and a cassava genomic library developed at CIAT. To date, CIAT has obtained several DNA clones, which may contain parts of the BE gene and is sequencing the clones to verify this. Confirmed clones will be used to "fish out" the complete gene from cassava genomic DNA.

Cassava Cyanogenesis

Understanding the biochemistry of cassava cyanogenesis has progressed significantly. Researchers at the University of Newcastle (UK) have cloned for linamarase, a key enzyme in the cyanogenesis pathway. When a transformation protocol is available, this cloned gene can be used to produce acyanogenic cassava genotypes for use in research on the role of cassava cyanogens and in plant breeding.

Researchers must first understand the implications of cyanogens for cassava production and use before applying results of cassava biotechnology research to cyanogenesis. For example, what is the role of cyanogenic glucoside compounds in the plant? Is there a relationship between root cyanogen content and processing quality? Although research on these topics has increased, much more is needed.

Postharvest Deterioration of Cassava

As cassava becomes more important as an industrial crop, the logistics of supplying fresh cassava to processing plants becomes more critical. Cassava roots that can be stored for more than a few days would let processors keep a reserve of raw material and thus operate more nearly at maximum efficiency.

A multidisciplinary approach has been outlined for addressing rapid postharvest deterioration of cassava roots, a significant production and marketing constraint. Four years ago this problem was insufficiently understood to be considered researchable. Now, if funds were available, research on cassava postharvest deterioration would integrate biotechnology, crop improvement, and recent advances in molecular genetics.

Microorganism-based Biotechnologies for Cassava

This new area of interest for CBN is well covered by other papers in these proceedings (Session 4).

Outlook

Experiences with other crops suggest that a genetic transformation protocol for cassava is not far off. Starch gene constructs, both publicly available and private, will probably be ready for testing in transgenic cassava plants as soon as a durable transformation protocol is available, pending observance of all applicable biosafety regulations. Work on the framework molecular map of cassava is in progress.

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Session 2:

Current Use and Future Potential

CHAPTER 4

STARCH POTENTIAL IN BRAZIL[1]

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Cassava Starch Production and Uses

Brazilian starch production is almost 1 million tons per year: 76% from maize (700,000 t/year), 23% from cassava (220,000 t/year), and the remainder from other crops such as potato and rice (500 t/year) (Ademir Zanella, 1992-1993, personal communication). Being traditional Brazilian foods, the last two crops are unlikely ever to play an important role in the starch market.

About 45% of maize starch is used raw (320,000 t/year), 40% as glucose and malto-dextrins (280,000 t/year), and 15% as modified starches (100,000 t/year). In contrast, about 68% of cassava starch is used raw (150,000 t/year), 18% as modified starch (40,000 t/year), 10% as sour starch (22,000 t/year), and about 3% as tapioca (8,000 t/year) (Ademir Zanella, 1992-1993, personal communication).

Because of its high quality and high value (US$1.50/kg), arrowroot will take a significant part of the future starch market. Cassava starch, in contrast, is a low-value product, with prices ranging from US$0.27 to US$0.40/kg (Ademir Zanella, 1992-1993, personal communication).

Annual world production of starch is currently about 29 million tons, obtained from maize (12 million), wheat (10 million), potato (4 million), cassava (0.8 million), and others (2.2 million) (Chuzel, 1991). The main starch producers are USA (maize), Canada (wheat), and the European Union (potato).

The USA imports 150,000 t of cassava starch, the EU 50,000 t, and Canada 10,000 t, representing only about 1% of world starch production, but 25% of the world's cassava starch production. Japan imports another 300,000 t of cassava starch (Lorenz Industry, 1990, personal communication). These countries use cassava starch to manufacture modified starches (Table 1).

Knight (1974) lists different starches and their use in food ("waxy" starch has a high level of amylopectin, a result of genetic modification):

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1. No abstract was provided by the authors.

Use	Starches used	Function
Spice for salads	Maize + "waxy" starch mixtures	Provide stability in acidity, cutting, and temperature
Filling for fresh-fruit pies	"Waxy" starch	Provides texture, transparency, and acid stability
Filling for frozen-fruit pies	"Waxy" starch	Provides stability in acidity and frozen texture (does not coagulate), and transparency
Maize-type cream	"Waxy" starch	Provides heat stability and high viscosity
Ready-made puddings	Maize + "waxy" starch mixtures	Provide stability in temperature, frozen texture, and cutting
Baby foods	"Waxy" starch	Provides stability in frozen texture and high viscosity

Table 1. Applications (in percentage) of cassava starch in USA and the European Union.[a]

Crop	Product					
	Glucose	Fructose	Alcohol	Paper	Modified	Raw
Maize	30 (40)	20 (20)	10 (-)	10 (10)	20 (20)	10 (10)
Wheat	50 (60)	30 (20)	10 (-)	- (10)	10 (10)	- (-)
Potato	- (-)	- (-)	- (-)	- (10)	90 (80)	10 (10)
Cassava	- (-)	- (-)	- (-)	- (-)	100 (100)	- (-)

a. Percentages in parentheses are values for the European Union.

SOURCE: Lorenz Industry, 1990, personal communication.

Brazil, the world's leading producer of cassava (Table 2), uses 80% of its production in food. Although the national production of cassava is spread over most Brazilian states (Table 3), northern and northeastern Brazil grow 67% of the national crop. Most is used as food—of the 1991 crop, only 4% was transformed into starch.

Table 4 compares cassava production in Paraná state with that in Santa Catarina: planting area in the first increased by 64%, as did production (65%), in the last 10 years. In contrast, in Santa Catarina, planting area dropped by 35%, as did production (-13%), because of environmental conditions and competition with the tobacco industry, which has a quicker turnover of crops (cassava takes 1 year to mature).

Cassava Starch Industries and Markets

Cassava starch industries are located in Santa Catarina, Paraná (78%), São Paulo, Minas Gerais, and Mato Grosso do Sul (Table 5) with 56 industries registered with the Associação Brasileira dos Produtores de Amido de Mandioca (ABAM, 1992-1993). But the founding of many new industries may have increased this number to 70. Processing capacity is variable, for example, the average is 221 t/day in Paraná state and 109 t/day in Santa Catarina. These industries have equipment of international standard.

The Centro Raizes Tropicais (CERAT), Universidade Estadual Paulista (UNESP), researched 12 cassava flour industries in Santa Catarina in 1993 through interviews, which showed an overall production of 10,450 t. These results, however, differed from ABAM's data of the same year (16,750 t).

Cassava starch production faces strong competition from maize starch, the prices of which are stable, and quality is high and consistent. Such competition inhibits the growth and expansion of cassava starch use. The structure of the maize starch market in Brazil is oligopolistic and is formed by three multinational enterprises: National Starch, Cargil, and Corn Products Corporation.

Maize and cassava starches are commercialized in the same markets: foodstuffs (cheese breads, cookies, ice-creams, chocolates, processed meat, and forcemeats), paper and cardboard, textiles, pharmaceutical products, glues and adhesives, and modified starches.

The biggest problem facing the cassava starch industry is a price variability that ranges between 60% and 70%. Prices for cassava roots

Table 2. World production of cassava roots (in millions of tons). Numbers are rounded.[a]

Producer	1961-1965[b]	1969-1971[b]	1991[c]
Major producers	50.0 (67)	63.5 (66)	99.4 (65)
Brazil	21.9 (29)	29.9 (31)	24.6 (16)
Thailand	1.7 (2)	3.2 (3)	20.3 (13)
Nigeria	7.2 (10)	9.4 (10)	20.0 (13)
Zaire	7.7 (10)	10.2 (11)	18.2 (12)
Indonesia	11.8 (16)	10.6 (11)	16.3 (11)
Other[d]	24.5 (33)	33.2 (34)	- -
Total	75.0 (100)	96.7 (100)	153.7 (100)

a. Values in parentheses signify proportion of total by percentage.
b. Compiled from FAO, 1990.
c. CIAT, 1993.
d. About 75 countries.

Table 3. Brazilian cassava production, 1991 crop, by region.

Region	Area (ha)	Output (t)	Proportion of national crop (%)[a]	Average yield (t/ha)
North	328,792	4,461,354	18	13.5
Northeast	1,132,889	12,005,948	49	10.5
Middle west	68,819	1,082,950	5	15.7
Southeast	134,775	2,118,052	9	15.7
South	277,835	4,862,480	19	17.5
Total	1,943,110	24,530,784	100	-

a. Numbers are rounded.

SOURCE: IBGE and CEPAGRO, 1992.

Table 4. Cassava production in the states of Paraná and Santa Catarina, Brazil, 1981-1993. Numbers are rounded.

Year of crop	Area (ha)		Growth rate (%)		Production (millions of tons)		Growth rate (%)		Yield (t/ha)	
	Paraná	Santa Catarina	Paraná	Santa Catarina	Paraná	Santa Catarina	Paraná	Santa Catarina	Paraná	Santa Catarina
1981/82	62,490		100		1.2		100		19.5	
1982/83	69,870		12		1.3		13		19.7	
1983/84	74,688		20		1.4		19		19.3	
1984/85	85,800	88,443	37	100	1.7	1.1	41	100	20.0	13.3
1985/86	85,800	84,812	37	-4	1.7	1.2	39	4	20.0	14.4
1986/87	85,445	75,738	37	-14	1.8	1.2	52	3	21.7	16.1
1987/88	85,242	69,469	36	-21	1.8	1.1	52	-1	21.7	16.7
1988/89	77,839	74,756	25	-15	1.6	1.2	33	9	20.8	17.2
1989/90	101,854	67,596	63	-24	2.1	1.1	79	-2	21.4	17.1
1990/91	102,265	63,370	64	-28	2.2	1.0	86	-13	22.1	17.3
1991/92	100,000	56,873	60	-36	2.1	1.0	72	-13	21.0	18.0
1992/93	137,000	57,379	119	-35	2.0	1.0	65	-13	19.6	18.1
								Average yield =	18.9	16.5

SOURCE: IBGE, various years.

Table 5. Brazilian starch production (in tons) for 1993, and estimated for 1994.

State	Starch industries (no.)	Production 1993	Estimated production 1994
Paraná	23	132,900	189,600
Santa Catarina	21	31,550	56,600
São Paulo	5	15,500	28,600
Mato Grosso do Sul	4	23,000	29,300
Mato Grosso	2	1,500	5,100
Espírito Santo	1	3,000	5,000
Total	56	207,450	314,200

SOURCE: ABAM, 1993.

varied erratically between US$19.50 (1983), $33.50 (1992), and $51.00 (1989) per ton during 1980-1992 (Ademir Zanella, 1992-1993, personal communication).

Other problems include the fact that the Brazilian cassava starch industries must also stop working for 4½ months/year. Low root production, a long vegetative cycle, and an inferior quality starch also make cassava starch production costly, compared with that of maize starch. In the last 3 years, maize prices have fallen against those of cassava roots, thus making the prices of maize starch more competitive and maize starch more available, and thus more used by industries (Venturini Filho, 1993).

Large Brazilian agroindustrial complexes that use starch as a raw material have invested in this area to guarantee an adequate supply of good quality and suitably stored starch. Three examples can be cited: National Starch in Santa Catarina and Nestlé in Paraná have just bought their own cassava starch industries. Fleischman Royal in São Paulo has used its own factory, Júpiter, to manufacture its own cassava starch for more than 5 years.

Figures 1, 2, and 3 show differences between the real prices of raw material (root), cassava flour, and raw cassava starch in Paraná. Prices of cassava starch (f.o.b. at factory) are more stable than those of cassava roots, which are vulnerable to the roots' perishability and fluctuate with root production. Products using cassava and maize starches are elastic, that is, income positive, whereas products from cassava flour are inelastic.

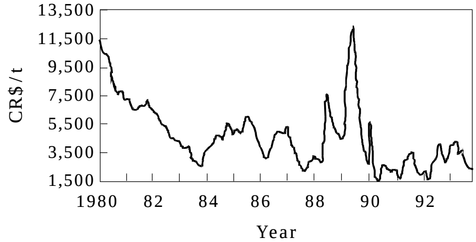

Figure 1. Cassava farmgate prices, Paraná state, Brazil. Correct prices until August 1993 by general price index-internal demand (deflator). (After Fundação Getulio Vargas, 1993, personal communication.)

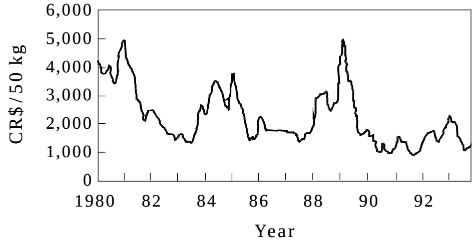

Figure 2. Real wholesale prices for cassava flour. Correct prices until August and September 1993 (after readjustment for inflation). (After ABAM, 1993.)

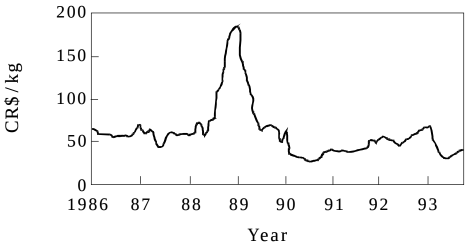

Figure 3. Real prices of raw cassava starch, industrial f.o.b., Paraná, Brazil. Correct prices until August 1993 by general price index-internal demand and in September 1993 after readjustment for inflation. (After ABAM, 1993.)

Although all Brazilian states produce cassava, only the states of the south (Santa Catarina and Paraná), southeast (São Paulo), and middle west (Mato Grosso do Sul) are technologically prepared to produce cassava starch.

Other constraints to expanding the cassava starch market include farmers' ignorance of the market, and lack of promotion of the virtues of cassava starch. Promotional pamphlets could be created by the CIRAD/SAR-UNESP project to target specific markets, potential markets, or growing existing markets.

An example of a growing market for cassava starch is beer manufacture (Venturini Filho, 1993). To make 7,400 g of beer, 474 g of cassava starch are needed. Brazilian beer production is 5.8 billion liters. Current mixes use malt with maize and rice grits. If the grits market could be divided into three to include cassava starch, a potential 120,000 t of cassava starch would be needed for this sector alone.

Acknowledgments

We thank Ademir Zanella of Halotek Fadel Industrial Ltd. for the data used in the tables.

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CHAPTER 5

PRODUCING CASSAVA FLOUR IN PERU AND ITS PROSPECTS FOR DEVELOPMENT[1]

S. Salas Domínguez, Y. Guzmán, and *S. Aquino**

Introduction

Concern is increasing worldwide about the social problems of poverty, unemployment, hunger, and mounting child mortality. In Peru, preliminary data from the most recent census shows that a population explosion has taken place in the last few years. This factor, together with Peru's sociopolitical and economic problems, has depressed living standards, especially in rural areas, which has to produce enough food to feed nine city dwellers for every rural inhabitant. But subsistence agriculture is prevalent because of agroecological constraints, lack of infrastructure, and lack of technical and economic resources.

More than two-thirds of Peru has agroclimatic conditions suitable for tropical crops that can grow in poor soils, with little fertilization, and are resistant to disease. Such crops have been rapidly distributed, and are the most valuable resource in fighting hunger and the greatest hope for rural development through agroindustry. Of these crops, cassava and plantain are the most important, both in the Peruvian Amazon and the humid tropics. The Instituto de Investigaciones de la Amazonía Peruana (IIAP) established a pilot plant for producing cassava flour in Pucallpa, capital of the Department of Ucayali, in the center of the Peruvian Amazon. This flour is used for human consumption and as a substitute for inputs used in plywood and bread-making industries.

Cassava Production in Ucayali, Peru

In 1991, national cassava production was 405,725 t, twice that of the 1950s. In contrast, other staples such as potatoes, wheat, and quinoa (*Chenopodium quinoa*) have decreased by one-third. Ucayali produces 20,000 t of cassava annually, fourth in national production. Consumption centers are located on different tributaries of the Ucayali River and, although tributaries are navigable, most cassava is wasted because distances are long, and boats slow and small. The highly perishable and bulky roots therefore do not reach markets in time.

Yields in the Departments of Loreto and Ucayali vary from 10 to 35 t/ha. The little produce that does reach urban markets has increased its price by 200% in relation to farmgate

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1. No abstract was provided by the authors.

prices. In rural areas, cassava is traditionally processed into products such as fariña and tapioca, but because of inferior quality, these products are not sufficiently competitive for urban markets.

In the past, plants for producing cassava flour were installed in Pucallpa and Iquitos (Department of Loreto, north of Ucayali). These failed mainly because the technology did not accord with the geographical and socioeconomic conditions of the respective areas.

The inhabitants of Ucayali eat sufficient carbohydrates to comply with the minimum nutritional requirements set by the National Nutritional Institute. That is, 142,350 t of roots and tubers and 98,550 t of cereals (mostly imported wheat flour) are consumed yearly.

The IIAP Cassava Flour Plant

Background

The farmers of Ucayali, especially cassava producers, confront severe socioeconomic and political pressures that often force them to emigrate en masse to cities or cocaine areas. In an attempt to keep people on the land, the IIAP looked for ways to propose and generate appropriate technologies, employment, and organization. The IIAP suggested integrating production systems to permit a more efficient and effective use of small-farm resources and thus improve production.

In 1989, the IIAP, with collaboration from CIAT (based in Colombia), began developing technology and machine prototypes for cassava processing. A plant was established at "Fundo Villarica," IIAP's experiment station at Pucallpa, despite a recession in almost all production areas, which occurred as a result of the 1991 political and economic emergencies.

The pilot plant was conceived as part of an integrated system. Activities were to complement each other so to increase potential and thus use more effectively available resources. The plant was to serve an area that suffers multiple problems, and the Peruvian Amazon was targeted.

The plant was complemented by vermiculture (farming of worms), agroforestry, fish farms. These activities not only provide a market for cassava products, but also help slow down the degradation of natural resources, for example, worm humus helps improve poor soils. The raising of small animals, based on products and byproducts of rural agroindustry (such as cassava flour), helps resolve the lack of protein in the regional diet. Efficient farm management (and thus higher productivity) reduces emigration.

Objectives

Through research, the plant was to generate and adapt technologies for processing flour, and evaluate and establish production and quality parameters. The plant, however, had to be a successful enterprise to interest farmers in the potential socioeconomic benefits of cassava flour production. Once farmers began participating, the plant was to offer training to cassava farmers and processors interested in integrating production, processing, and marketing.

To fulfill its functions of technological research, flour production, product promotion, and training, the plant had the following objectives:

(1) To validate, adapt, and generate technologies for processing cassava and its products.
(2) To open markets for cassava-based products such as flour, flakes, and grains.
(3) To integrate the use of the entire cassava plant in animal feed.
(4) To increase the value of cassava roots, which are underused because of their perishability.
(5) To gradually substitute imported wheat flour.
(6) To provide technical and organizational training for farmers and mid-level technicians.
(7) To encourage farmers to not only produce cassava, but also to process and market it.

Plant facilities

The plant had four sections: (1) reception, storage, and preparation; (2) washing; (3) chipping; and (4) preliminary sun-drying, artificial drying, milling, and storing the final product. The area for storing and preparing raw material was built on higher terrain than was the chipping area to make use of gravity in transferring raw material. The dryer was a tray system used by CIAT, with a burner that, for fuel, used wood discarded from sawmills.

To reduce drying time, flakes destined for animal feed were first dried in trays, and then sun-dried. The basic machinery was brought from Colombia, but accessories and other equipment were built locally and elsewhere in Peru. The total investment was US$27,000, including buildings, machinery, and other equipment.

From the start, the IIAP encouraged the organized participation of cassava growers so they could evaluate the possibilities of other plants under similar direct management, and so sign agreements that permit mutual collaboration. Supplies of raw material came from some sectors of the Campo Verde district, near Pucallpa.

Plant operation

The plant operated at 60% capacity, in accordance with the goal set. The following five cultivars were used: Señorita, Huangana, Huanuqueña, Arponcillo, and Nusharuna. Best results have been obtained with cv. Señorita with a yield of 3.2:1 (root to flour), but is more perishable than other roots (lasts 2 days). Cultivar Nusharuna has the most durable roots but its yields are low, 3.9:1, and the flour is darker because the peel is difficult to remove.

The percentage of loss from root defects after selection and preparation was high (15%). Although this problem could be overcome by differentiating root prices, farmers had to be taught the need for selection.

Overall, the equipment performed well, except for the screen and dryer. The minimum drying time achieved was 12 hours, including preliminary sun-drying. Raw material accounted for 85% of production costs, fuel 7%, and labor 3%. Packaging, depreciation, and maintenance accounted for the remaining 5%.

Marketing

The plant targeted the local market, with some initial promotion in Iquitos and Lima. Currently, demand is 70 t of flour per month, of which only 16 t could be supplied. About 60% of production is sold to bakeries (which substitute as much as 20% of wheat flour) through the Programa Nacional de Alimentación (PRONAA) and to the private company, Cotrip, that makes water biscuits. About 20% goes to plywood industries, 5% to Lima, and another 5% to Iquitos. The bran, together with discarded roots, is used for animal feed.

Key market segments at a national level are still to be identified, and competition from imported wheat flour has to be resolved. Ucayali, for example, uses 700 t/month, of which 80% is for bread making and 20% for plywood industries.

Research

The plant lacked laboratory equipment for quality control, which was done by several universities and nongovernmental organizations (NGOs). Proximal and microbiological analyses were carried out.

At first, because water quality was inferior and vermiculture was located near the plant, microbiological quality was poor. Scientists found fungi, yeasts, fecal coliforms, and clostridium sulfite reducers in quantities above permissible levels, but no *Escherichia coli* nor salmonella. These problems have been identified and solved, and the flour is now acceptable for human consumption.

Dry matter content of cv. Señorita is 34%. On the average, whole cassava flour contains 84.2% starch, 1.4% protein, and 3.1% fiber.

Based on experiences in bread making, trials were conducted with bakeries to establish the following formula for bread preparation:

Wheat flour	80 parts	Yeast	3 parts
Cassava flour	20 parts	Additive	1 part
Sugar	6 parts	Salt	1 part
Fat	6 parts	Water	30 parts

Color still has to be improved but flavor and consistency are good. Currently, artisanal modules for making bread and pasta are being installed to promote the establishment of similar projects in different rural sectors.

Training

Training focuses on three levels: (1) university theses; (2) training rural dwellers to become qualified workers, or, through modular training courses, knowledgeable on any phase of the process; and (3) courses for the public, such as bread making for commercial bread makers and housewives.

Achievements

After 2 years of operation, the plant successfully:

(1) Identified, analyzed, and improved native technology.
(2) Built the production infrastructure, using locally available resources. Machines and equipment were simple, versatile, and adaptable to processing other products, such as plantains, "sachapapa" or taro, and cassava.
(3) Produced flour that was US$0.25 cheaper than wheat flour.
(4) Found favorable local and regional markets. These were vermiculture, agroforestry, raising of small animals, horticulture, and pisciculture.
(5) Made the new technology economic for small-scale farmers to invest and rapidly recuperate their investments, thus diminishing risks when conditions become unfavorable.
(6) Established a modular system for installation and operation, thus enabling each phase of the process to be totally independent and thus more efficient.
(7) "Passed the test" of adverse political and economic conditions, including violence, recession, and generalized poverty.

Prospectives

An agreement has been signed with the Alto Huallaga Special Project to introduce integrated production systems as an alternative to cultivating coca. Currently, the plant at Tocache is being installed, with CIAT's assistance. With collaboration from Caritas Peru, four plants will be established in Puerto Maldonado (southeast Peru), Iquitos and Yurimaguas (Department of Loreto), and Tumbes (north coast).

CHAPTER 6

CASSAVA STARCH IN NORTHERN CAUCA, COLOMBIA: SOCIOECONOMIC EVALUATION OF ITS PRODUCTION AND COMMERCE[1]

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Introduction

Cassava plays a major role in subsistence farming in northern Cauca, Colombia. About 90% of root production is used for extracting sour starch, and as much as 80% of sour starch production is used for making the breads "pandebono" and "pandeyuca." Sour starch has its own characteristic functional properties, flavor, and aroma.

In northern Cauca, cassava starch extraction is mainly an artisanal activity, although processing plants are mechanized to some extent. In importance, this agroindustry ranks third after the sugar, and editorial and publishing industries.

Our study aimed to better understand the different problems affecting cassava starch production in the region, and help researchers identify priority needs for possible technology intervention.

The study is part of a research and development (R&D) program on cassava starch production being conducted by CIAT's Cassava Utilization Section. The program's objective is to offer technological alternatives to small-scale, cassava starch producers. The program first began in 1989, and is based on an informal network comprising various Latin American laboratories and institutions involved with cassava starch production. The program also comprises regional working groups that evaluate technology for starch production, study the technical and economic system, characterize and evaluate products, treat waste waters, and conduct basic research on fermentation and raw material (Chuzel, 1991).

Objectives of the Study

The general objective was to characterize starch production and commerce in northern Cauca, Colombia, and so assess the technical and economic performance of small-scale, cassava starch factories.

Specific objectives were:

(1) To statistically analyze the surveys carried out by the Cassava Utilization Section in 1990 on the technical performance of

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1. No abstract was provided by the authors.

small-scale, starch factories, and to study the economic performance of these and their social implications. The economic survey of starch factories carried out by university students was used as a base.

(2) To characterize the production process of cassava processing plants and determine the capacity of installed plants.
(3) To identify the seasons when supplies of cassava sour starch are abundant or limited and determine distribution channels.
(4) To analyze social characteristics related to starch production and commerce.
(5) To identify factors limiting starch production and commerce.

Methodology

The study began by surveying small-scale, sour-starch producers and middlemen. The target population consisted of 99 small-scale starch factories, first surveyed in 1990 when the R&D project began, in the towns of Santander de Quilichao (86 factories) and Caldono (13). Of this group, 35 processing plants were selected and, for reasons of efficiency, stratified according to plant size (small = fewer than 3 workers; large = 4 or more), age of equipment (new = purchased in the last 15 years; old = more than 15 years old), and geographic area (municipality of Santander de Quilichao or Caldono).

Selection was randomized, but proportional to stratum size. The Stratified Sampling of Elements technique (Pardo Camacho, 1991; de Servín and Servín Andrade, 1978), which gives proportional allotment, was used for sampling.

Cassava starch middlemen were surveyed in Caldono, Santander de Quilichao, and Cali. Because no census of middlemen existed, no specific sample was established. The survey was therefore based on a list of 35 middlemen identified in the previous survey on small-scale, cassava starch producers; of these 35 middlemen, 20 were surveyed.

Numerous problems arose in obtaining comprehensive information, especially that on the volume of starch purchases and sales. Because middlemen were so reluctant to share information on how they managed their businesses, a case study was conducted, based on information supplied by the COAPRACAUCA Cooperative, Santander de Quilichao.

Starch Processing and Commerce

Root production is a key aspect in the processing and commerce of cassava starch in northern Cauca. Although roots are used more to obtain starch than for human consumption, when market prices drop below the average Col$32/kg (US$0.05/kg), then fresh cassava is sold to cassava drying plants for use in animal feed.

In the Cauca Department, 6,290 ha were planted to cassava in 1991, producing 71,624 t at a yield of 11,387 kg/ha (Departamento Administrativo Nacional de Estadística, Colombia, 1992, unpublished data).

The municipalities of Buenos Aires, Santander de Quilichao, and Caldono planted 4,080 ha of cassava, accounting for 64% of the total area under cassava cultivation in Cauca. Production reached 39,000 t, 54% of the department's total production. Yields were 9.5 t/ha, almost 16% below the departmental average of 11.3 t/ha. But only 2.3% of the national crop (173,999 ha) is planted in Cauca because the root's perishability, and its low and fluctuating prices, among other factors.

The amount of cassava on offer to small-scale, starch factories averages 556 t/year, for a consumption of 456 t/year at Col$32,000/t (US$47.00). Although shortages of raw material occur in Cauca at certain times of the year, the annual supply of cassava often exceeds demand, especially for 18 of the factories in Santander de Quilichao. Located close to the Pan-American Highway, they tend to be oversupplied.

Plant production during 1990-1991 was irregular: some plants operated sporadically, according to the availability of raw material and working capital. For 1990, the average minimum production was 4.3 t of starch per week and the maximum was 175.0 t.

For 1991, the plants had an average production of 420 t of starch per year (8.7 t/week) and a maximum of 775 t/year (16.1 t/week). Such figures indicate that the plants do not work at full capacity because of the lack of raw material in the area. Production recession caused by lack of raw material can last from 2 to 12 weeks. Of the processors, 51% stated that they required a constant amount of raw material.

Yield

In 1991, sour-starch production per factory decreased considerably, averaging 97 t/year. Byproducts were bran (fiber and peel left over from sieving starch) at 42 t/year and "mancha" (scum skimmed off surface of sedimented starch) at 8 t/year. Most small-scale, starch factories carry out sweet-starch extraction on request, but production is sporadic because starch quality does not always reach industrial technical specifications. But, at the time of the survey, only one factory was producing sweet starch (1.2 t/week).

The decrease in sour-starch production in 1991 was caused partly by a lack of both raw material and working capital. At the same time, the Colombian Government began implementing a policy of "open economy." Bank credits were closed to stabilize inflation at 22%. From August 1990 to September 1991, the 33 starch factories under study processed 16,878 t of starch, producing 3,207 t of sour starch, 1,333 t of bran, and 270 t of "mancha." That is, every 100 kg of roots yielded 19% starch, 8% bran, 1.7% "mancha," and 71.3% of both water (which comprises 65% of roots) and waste, that is, peel and starch lost to inefficient processing techniques. Yield differences among factories are caused by, for example, cassava variety, harvest age, and postharvest handling.

Producers can obtain as much as 27% starch (wet basis) with 60% technological efficiency, according to experiments by the Corporación para Estudios Interdisciplinarios y Asesorías Técnicas (CETEC), a Colombian organization that provides technical assistance to starch-producing farmers. Once the product is processed to 12% moisture content, these values can be obtained per 100 t of cassava. For small-scale, starch factories in northern Cauca, the cassava-to-starch conversion ratio is 5:1. The 200 small-scale, starch factories of this region therefore produced a total of 8,500 t of sour starch in 1994.

In Ecuador, the cassava-to-starch conversion ratio is 5-10:1. This ratio varies greatly according to the time of year and cassava varieties used. Byproducts (bran and "mancha") are sold for animal feed (Chuzel, 1991).

In Minas Gerais, Brazil, the "polvilho azedo," or sour starch, enterprises can process from 1 to 40 t of cassava roots per day. Annual production ranges from 20 to 1,000 t/year, and yields from 200 to 300 kg of starch per t of roots (Oliver Vilpoux, 1992, personal communication).

Procedures, Equipment, and Maintenance

In Colombia, small, semicommercial, cassava starch factories are called "rallanderías." These factories typically have a grater-sieve and washer-peeler, both motor-driven. Their processing capacity ranges between 4.4 and 44 t of roots per week, with an overall average of 16.2 t/week. Figure 1 demonstrates processing in a medium-sized, starch extraction factory, beginning with the acquisition of roots.

Root supplies. Small-scale starch processors do plant cassava, according to surveys carried out in 1990 by CIAT's Cassava Utilization Section. From August 1989 to August 1990, the total area planted to cassava by processors averaged 106 ha, of which 43% corresponded to the processors' own plots and 57% to rented plots. For 1991, the percentage of processors renting land for cassava cultivation decreased to 54%. That same year, the total area planted to cassava by the 99 starch processors averaged 80 ha. Thus, in the two municipalities, the 26 ha planted to cassava the previous year were destined for other purposes. Furthermore, of the 51% growing cassava, only 33% owned the land and 18% rented it; 48% lack land title deeds, which reduced access to credit. The cost of leasing 1 ha ranges between Col$3,000 and Col$40,000 (US$4.43-$59.00) per month, averaging Col$10,333.00 (US$15.34) per small-scale, starch factory.

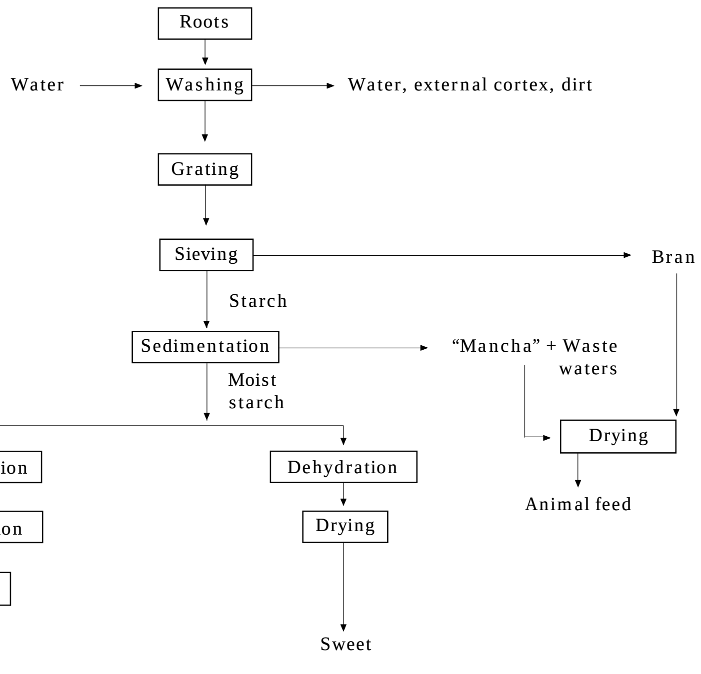

Figure 1. Processes performed in a medium-sized, cassava-starch extraction factory, northern Cauca, Colombia. (Modified after Chuzel, 1991.)

Washing and peeling. These are done either manually or in a rotating drum. Of the survey respondents, 93% have mechanized these operations, thus reducing women's participation in processing. Before, women were employed to peel the roots.

Grating. Grating is carried out by rotors with perforated laminae that are changed periodically. About 36% of factories change the laminae every 90 days, 23% every 60 days, 21% every 30 days, and the rest more than 90 days.

Sieving. The starch dissolved in water is separated from the pulp or bran, which is later used in animal feed. Different types of fabric, placed on rotating screens, are used for sieving, the most common being nylon (58%), canvas (28%), and silk (3%). The fabrics are changed frequently: 77% of processors change them every 30 days, 11% every 60 days, and the rest after 90 days. For 89% of the plants surveyed, sieves are less than 10 years old.

Sedimentation. The slurry from sieving is left to settle. Particles of fiber and other fine materials that had not been removed during sieving are separated to form "mancha," another byproduct used in animal feed. Sedimentation is carried out in concrete tanks veneered with wood or glazed tile. On the average, processing plants have five sedimentation tanks, each with an average capacity to hold 551 kg/day.

Fermentation. To obtain sour starch, the moist starch is passed through a series of tanks, where it remains 15 to 20 days until the desired acidity is reached. The average factory has five fermentation tanks, each with a capacity of 1,030 kg. Sweet starch is obtained by dehydrating and sun-drying the moist starch after sedimentation.

Drying. Starch is usually sun-dried on trays or terraces, or on concrete floors previously covered with plastic to prevent farmyard contamination. The dried starch is then packed for market distribution.

Commerce

The typical distribution of cassava sour starch begins with the cassava farmer who sells the roots either to middlemen or directly to the starch processor. Only 7% of processors surveyed purchase roots only through middlemen; 65% buy directly from the farmer, and 28% from both. Starch is also distributed through middlemen or directly to users. The middleman sells to the wholesaler or retailer who, in turn, distributes to intermediate consumers such as bakeries and industries that, in their turn, distribute their products directly to consumers or to distributors of processed food products (Figure 2).

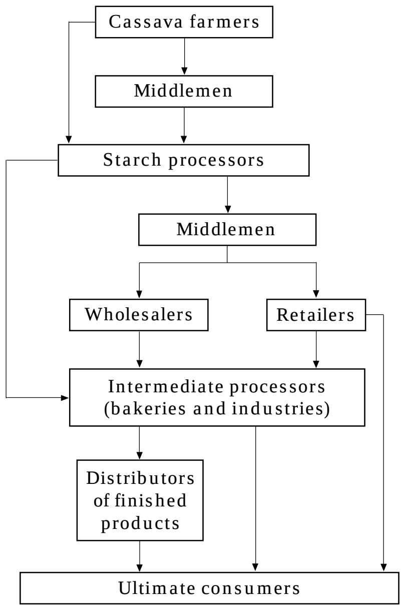

Figure 2. Typical distribution chain for cassava starch in northern Cauca, Colombia.

Starch processors sell most of their products in cash but may sell on credit to regular clients. These clients also pay the processor in advance when they urgently need starch and the processor does not have enough working capital to fulfill the demand. A credit period is usually 19 days. Although commercializing products is difficult, stocks rotate quickly. Sour starch is stored for an average of 10 days, sweet starch 8 days, bran 11 days, and "mancha" 14 days.

Processors also distribute sour starch through the COAPRACAUCA Cooperative, which groups about 30 small-scale, starch processors of the region, and through middlemen. The cooperative and intermediate middlemen, in turn, sell the starch to wholesalers and retailers who then distribute the product to major markets in the cities of Santander de Quilichao, Cali, Buga, Cartago, Tuluá, Pereira, Ibagué, Medellín, Bogotá, Cartagena, and Montería.

The municipality of Santander de Quilichao has the highest number of middlemen—which explains why 42% of starch processors sell their product there—followed by Caldono and Cali, each with 15%, and the other cities with 28%. For 1991, the average price per kg of sour starch was Col$230 (US$0.39). The byproducts (bran and "mancha") are usually sold on the retail market in Santander de Quilichao, being mainly used for animal feed (Figure 3).

Economic Evaluation of Small-scale, Starch Factories

Table 1 shows the costs involved in producing sour starch. All small-scale, starch factories are mechanized to a certain extent so electricity is necessary. An average factory pays US$220/year for electricity, accounting for 1% of total costs. Because the factories must periodically change some of

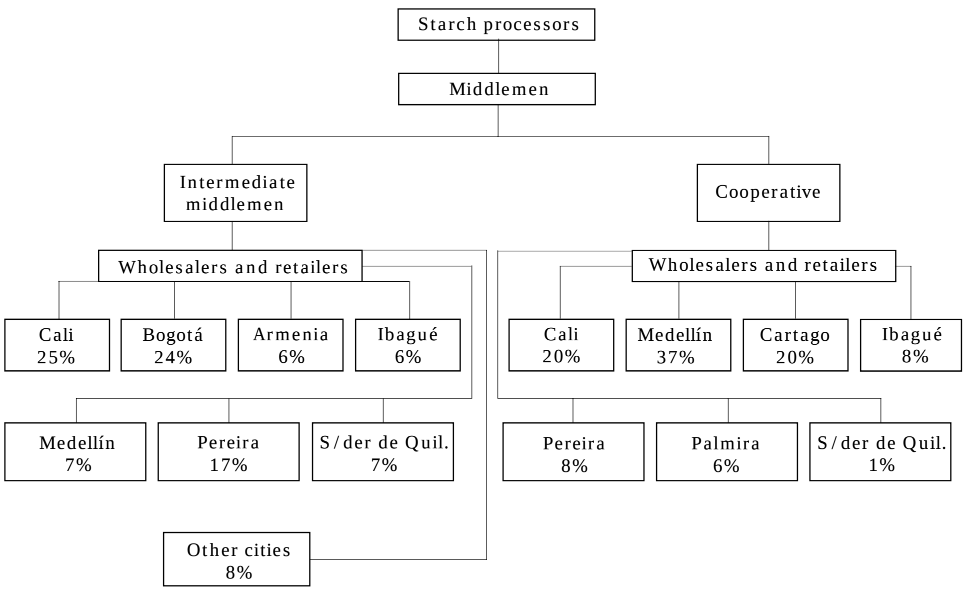

Figure 3. Market channels of cassava starch in northern Cauca, Colombia. (From interviews with COAPRACAUCA Cooperative members.)

Table 1. Annual average costs involved in producing cassava starch (1991), northern Cauca, Colombia.

Item	Col$	US$ (1991 value)	Percentage of total costs
Fixed costs	2,882,000	4,836	12.1
Energy	131,000	220	0.5
Maintenance	487,000	817	2.0
Rent	1,082,000	1,815	4.6
Administration	855,000	1,435	3.6
Others	327,000	549	1.4
Variable costs	20,632,000	34,618	87.9
Raw material	16,708,000	28,034	71.5
Labor	1,751,000	2,938	7.4
Transport	1,958,000	3,285	8.0
Packing	215,000	361	1.0
Total costs	23,514,000	39,454	100.0

the equipment they incur maintenance costs equivalent to 2% of total costs.

Small-scale, starch producers save money when they own the factory rather than rent its premises (CIMMYT, 1993). Rental costs depend on the factory's location in the region, but these are normally low, with little tendency to increase. Only two of the starch processors surveyed had explicit rental costs, accounting for 5% of total costs.

Administrative costs account for 4% of total costs. Usually, the owner himself manages the factory, this being his means of support. An undetermined amount of the earnings from the sale of starch is used for household expenses, that is, as his salary. This fact, perhaps, most influences the efficient operation of the factory.

Administrative costs are closely related to the efficiency of any enterprise. A small-scale, cassava starch factory should have a dedicated manager with sufficient expertise to administer the factory during production time. The manager should be assigned a salary and, even though some starch processors feel that this represents an extra cost, it would guarantee more efficient operation.

Of the 99 small-scale, starch factories operating during the study, three had administrative costs that exceeded labor costs. In most cases, labor costs were notably greater than administrative costs, indicating that a balance does not exist between these two that would ensure a distribution of the economic benefits of small-scale, starch factories.

The cost of buying and transporting raw material account for 71% of operating costs. Several small-scale, starch factories are located where it is easy to purchase large volumes of low-quality cassava, especially in flat areas, thus reducing the average purchase price per kg of raw material. In 1991, average freight charges were Col$1,958,000 (US$3,285), accounting for 8% of total costs and exceeding administrative and labor costs.

Labor accounts for 7% of total costs. Labor is inexpensive, and small-scale, cassava starch factories provide a significant source of employment. In several rural communities of the region, these factories are the rural population's only source of income. Labor is also seasonal, being scarce during coffee harvest. Most factories' busiest time is during cassava harvest.

Income Generated by Sour Starch Sales

Processors sell everything they produce, with sour starch bringing the highest yearly income of Col$22,942,000 (US$38,493) or 89% of the total income. Byproducts brought Col$2,909,000 (US$4,881) or 11% of the total income. Net profit per factory was estimated at Col$2,337,000 (US$3,921), and the net profit per ton of sour starch was Col$24,300 (US$41).

Cost-to-Benefit Ratio

Profitability of cassava starch processing was compared with the interest that the local agricultural bank (Caja Agraria) pays to savings accounts (21% per year in 1991) as a measure of opportunity cost. The return on starch processing was only 12%, although the opportunity interest was 21%. That is, the processor lost 9%.

Profits generated by this type of small enterprise are therefore operative in nature, not financial. Most small-scale, starch processors earn only enough to satisfy their basic needs. Without an economic surplus to reinvest in their business, processors cannot readily modernize the infrastructure. Processors continue to participate in the market because their basic necessities and fixed costs are covered and they can continue to sustain themselves in the market despite the lack of profits for reinvestment.

Processing Constraints

Major constraints found in cassava starch processing are:

Irregular cassava supply. A major constraint is irregular cassava supply (Table 2), which is caused by inconstant cassava production, which itself is related to unstable cassava prices. As cassava prices rise, farmers intensify cultivation, thus increasing supply and lowering prices. Processors do not control the flow of raw material required to initiate the process; if they did, they could plan production according to the market and the output of each plant.

Working capital. The lack of timely credit limits sour starch production and its subsequent commercialization. Of the processors, 61% had plans to obtain credit with a bank. This credit was to pay suppliers for raw material and to improve the infrastructure, not only for plants that process both coffee and cassava, but also housing for the processors.

Often this credit is used for purposes other than those indicated in the initial request. The factory is soon left without working capital and has to resort to informal lines of credit such as suppliers giving extra days to pay. Middlemen may also lend money to the processors, with the compromise that, once the starch is processed, it

Table 2. Constraints to cassava starch processing, northern Cauca, Colombia.

Constraints	Responses by processors	
	(no.)	(%)
Irregular supply	27	57
Supply vs. demand for starch	6	12
Working capital	6	12
Lack of water (climate)	6	12
Tank capacity	3	6
Total	48	100

will be sold to them at favorable prices. Many loans granted by middlemen are used to make down payments to cassava farmers to ensure root supplies.

Tank capacity. Tank capacities are often very limited: on the average, a factory will have five fermentation tanks with an average capacity of 1 t each, and five sedimentation tanks with an average capacity of 551 kg each.

Stock of spare parts. Small-scale processors do not keep a stock of spare parts needed to maintain their equipment, often causing holdups in starch production.

Commercial Constraints

Factories are affected by different combinations of several major commercial constraints (Table 3); these are:

Transport. Remote rural areas characteristically have deficient transport facilities, which delay deliveries. Starch processors are thus often obliged to rely on middlemen, which may go against their own interests.

Plant site. Starch processors locate their processing plants according to where land is available, rather than where consumers are situated. Control over the product is therefore lost and the distance between the two ends of the system (supply and demand) grows and so does the chain of middlemen participating in the commerce.

Starch quality. Processors have few standard ideas on starch quality, making it difficult to determine criteria for product quality. For 97% of the surveyed processors, fermentation is important; this process should take from 15 to 20 days. For 70% of processors, cassava variety is also a major criterion. But processors tend to select varieties with high starch yields rather than for quality, partly because working capital is insufficient for purchasing the more expensive, high-quality starch varieties (Table 4).

Water. During summer months, water is scarce and, in winter, processors have difficulty in drying and transporting the starch. For 78% of surveyed processors, water quality is an important criterion: it should be cold. The water used by 60% of the surveyed processors comes from streams and is untreated before use,

Table 3. Constraints to cassava starch commerce in northern Cauca, Colombia.[a]

Constraints	Factories affected	
	(no.)	(%)
Transport	15	15.2
Location	9	9.1
Availability of raw material	36	36.4
Availability of credit	24	24.2
Starch quality	33	33.3
Climate	33	33.3
School vacations	21	21.2
Others	39	39.4

a. Total number of starch factories surveyed (weighted data) = 99.

Table 4. Processors' criteria for quality in cassava starch, northern Cauca, Colombia.

Criterion	Factories using criterion[a]	
	(no.)	(%)
Color	33	33.3
Fermentation time (acidity)	96	98.0
Starch grain	54	54.5
Cassava variety	69	69.7
Age of cassava	30	30.3
Water quality	78	78.8
Climate	9	9.1
Others	30	30.3

a. Total number of starch factories surveyed (weighted data) = 99.

thus contributing to low product quality.

Processors' knowledge. The limited technical knowledge that cassava farmers have of starch quality, and its processing and commerce, also negatively affects this agroindustry.

Social Characteristics Related to Cassava Starch Production and Commerce

The following social issues are involved in the cassava starch agroindustry:

Improved living standards for rural, small-scale, starch producers and of the region as a whole. Table 5 shows that the starch agroindustry benefits both the people directly involved in the industry and the entire northern Cauca region. This small-scale enterprise increases the number of jobs (according to 76% of the processors surveyed) and better uses available resources in the region, thus considerably energizing the economy of the Valle del Cauca Department. The region is becoming a center of development for the entire Department, favored by its proximity to Cali, capital of the Department. Cali provides resources needed by small-scale starch factories, particularly spare parts for equipment and financial resources.

Industrial security. Adequate industrial security, to reduce risks for employees during processing, does not yet exist within the organizational structure of small-scale starch factories. Processors usually do not appreciate the risks and diseases that can occur during starch processing and rarely take minimum protective measures.

Colds comprise the commonest ailment (according to 39% of surveyed processors), a result of personnel not wearing dust masks during drying and packing (Table 6). The personnel in charge of sieving should be fitted with gloves and goggles; 27% have suffered either cuts or eye ailments. Drying sites located in high places, such as the "eldas" (sliding overhead screens), should be constructed with protective banisters to prevent fractures and blows.

A related problem that affects production continuity is frequent "Monday absenteeism" as a result of hangovers after heavy drinking.

Table 5. How the cassava starch agroindustry contributes to the economic well-being of the individual family and of the region, northern Cauca, Colombia. Responses from a survey of 99 households.

Socioeconomic criterion	Family		Region	
	(no.)	(%)[a]	(no.)	(%)[a]
Overall improvement	99	100	99	100
Increased education	51	52		
Improved housing	69	70		
Improved living standards			48	49
Vehicle ownership	27	27		
Improved roads			3	3
Increased income	66	67		
Jobs			75	76
Others	21	21	24	24

a. Percentages are rounded off.

Table 6. Incidence of diseases and accidents in small-scale, starch factories, northern Cauca, Colombia.[a]

Complaint	Factory reporting	
	(no.)	(%)
Ailment[b]		
Cold	39	39.4
Backache	3	3.0
Eye problems	3	3.0
Sinusitis	3	3.0
None[c]	27	27.3
Accidents		
Fractures	9	9.0
Cuts	27	27.3
Blows	3	3.0
None[c]	60	60.6

a. Total number of starch factories surveyed (weighted data) = 99.

b. A problem that causes absenteeism and industrial accidents is the hangover. Twenty-four (i.e., 24%) factories reported on this problem.

c. That is, the factory either did not know, or did not answer.

Environmental contamination. About 85% of residues produced during starch extraction are deposited in the streams (40%), rivers (27%), and ravines (18%) near the factories. Another 12% is used as manure, and 3% enters the sewerage system. As a result, the agroindustry noticeably contaminates the region's rivers and affects its inhabitants' health. Even the processors themselves use this same water for washing, drinking, and cooking, as well as root processing. The contaminated water also affects starch quality and thus the processors' income.

Given their usually low educational level, processors do not appreciate the importance of caring for rivers or for the adequate disposal of residues. To reduce environmental contamination, the departmental government and different institutions interested in regional economic and social development need to intervene. For example, CETEC is conducting studies on treating waste waters.

Conclusions

Some conclusions from the study are:

(1) Cassava starch production is of major importance in northern Cauca, with 90% of cassava roots produced destined for starch production.
(2) Major constraints are, for starch production, irregular supply of cassava, lack of timely credit, and maintenance of equipment; for starch quality, quality of water used, fermentation time, and variety and age of cassava; for commerce, starch quality, climate, and transport.
(3) Small-scale processors cannot fix starch prices, which therefore obey the laws of supply and demand. Cassava farmers need assistance in ensuring a constant supply of roots for processors, which would help control price fluctuations.
(4) Cassava starch production offers socioeconomic benefits such as employment. In 1990, 422 people and, in 1991, 345 people were employed.
(5) Over the long term, this study is expected to benefit about 3,000 households that subsist on this agroindustry. Once they understand and efficiently manage the production and commerce of cassava starch, these families will have better opportunities of participating in the market and improving their social well-being.

Recommendations

The following list of recommendations aim to help guide experts intervening in technical, economic, and scientific decisions on behalf of cassava starch processors.

(1) Small-scale cassava starch processors working in rural areas should be encouraged to plan staggered crops by taking into account the vegetative period of the varieties they select. The crop should satisfy, at least partly, the factory's requirements for raw material so that it may reach equilibrium point or higher. The remaining amount can be obtained from third parties within the factory's area of influence by providing incentives to cassava farmers.
(2) Differential prices for cassava roots should be fixed, depending on quality and yield. This policy will allow processing plants to operate more economically.
(3) Additional technical, financial, and administrative support, adapted to the processors' socioeconomic level, is needed. The processors can then benefit from real improvements in their enterprise's infrastructure and organization.
(4) Operational schemes that maintain labor and administrative costs at acceptable levels should be incorporated. The small-scale, starch factory can then achieve equilibrium and will operate acceptably and economically.
(5) Measures should be taken to improve factory infrastructure, thus improving cassava starch production while better conserving the waterways. Examples of such measures are draining defined areas and conserving riversides to prevent erosion.
(6) Activities aimed at improving the population's standards of living are also needed in such areas as health, education, housing, and public services.
(7) The local government and communities should be encouraged to provide potable water for human consumption and for use in small-scale, starch factories.
(8) Farmer associations should be encouraged to stimulate their members to negotiate more and participate in setting cassava starch prices. Farmers would then have increased financial, operative, and administrative capacity; be able to handle their own trading needs; and better understand market behavior.

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CHAPTER 7

CASSAVA STARCH AND FLOUR IN ECUADOR: ITS COMMERCIALIZATION AND USE

*Carlos Egüez**

Abstract

In Portoviejo, Ecuador, the Unión de Asociaciones de Trabajadores Agrícolas, Productores y Procesadores de Yuca (UATAPPY) produces cassava starch and flour for a wide variety of products, including animal feed, corrugated cardboard, plywood, cassava bread (*pandeyuca*), baked products, and ice-cream cones. The amounts of cassava starch or flour incorporated vary according to intended use. The most common uses are filling in plywood, carbohydrate source in balanced animal feeds, and as binder in cardboard boxes and shrimp feeds. Ecuadorean industries are beginning to appreciate the potential advantages of these products. Recent studies estimate that the potential demand greatly exceeds the current supply, which augurs well for cassava root processors.

Introduction

Attempts to produce cassava flour and starch at the industrial level in Ecuador have been unsuccessful, because either factories were poorly located in relation to production zones, or national or imported raw materials were cheaper. In contrast, small-scale cassava starch extraction dates back to early this century, while flour processing began 8 years ago.

About 200 family-run processing units or "rallanderías" currently produce between 2,500 and 4,000 t of cassava starch per year. The technology of drying cassava chips to produce flour was introduced from Colombia to Manabí Province, Ecuador, in 1985, and has been adopted mainly by the Unión de Asociaciones de Trabajadores Agrícolas, Productores y Procesadores de Yuca (UATAPPY), which produces 1,000 to 1,500 t of flour per year.

The Ecuadorean Integrated Cassava Program, consisting of UATAPPY and several national and international institutions, has produced 10 different cassava products with a wide marketing range, including exports to Colombia over 2 consecutive years.

The commercialization of UATAPPY's products has allowed it to continue its activities. But market expansion and consolidation remains difficult as Ecuadorean industries continue to use other starchy raw materials that are sometimes

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Table 1. Comparison of current prices of cassava byproducts with wheat flour and maize starch in Ecuador (factory prices).

Cassava product	Current price (US$/t)	Other product	Current price (US$/t)
Cassava meal	175		
Sieved whole flour	231		
White cassava flour	236	Wheat flour	352
Sieved white flour (for human consumption)	275		
Starch (for human consumption)	660		
Industrial starch (first grade)	440	Domestic maize starch	400
Standard industrial starch (second grade)	363	Colombian maize starch (placed in Ecuadorean factories)	305
Starch bagasse	113		
Bran of sieved flours	88		

SOURCE: UATAPPY, 1993, personal communication.

Table 2. Demand for wheat flour and maize starch by several markets, and current sales of cassava products, Ecuador.

Product	Market	Annual demand (t)	Current sales
Wheat flour	Balanced shrimp feed	25,000	0
	Lumber industries	2,400	256
Maize starch	Cardboard factories	6,000	0
	Colombia	?	200

SOURCE: Susan Poats, 1993, personal communication.

subsidized, such as wheat and maize starch (Table 1).

Persuading industrial managers to use cassava products—sometimes the *same* product—instead of traditional materials for a wide variety of individual uses has also been difficult (Table 2).

The situation is improving, however, with the current "free market" conditions, which allow cassava products to be more competitive in terms of quality and price.

Descriptions and Uses of Cassava Products and Byproducts[1]

Cassava meal is a coarse, brown powder obtained from unpeeled chips, sun-dried on concrete, and ground in a hammer mill. It is used as a carbohydrate source in balanced feeds, and as a pellet binder in shrimp feed, replacing wheat flour and synthetic binders and forming 2%-12% of the formula, depending on the manufacturer.

1. The cassava products and their uses as described here are not registered; they reflect the author's research at processing and industrial levels in Ecuador.

Sieved whole flour is a very fine off-white powder obtained by sieving meal through a no. 60 mesh. It is used in plywood, replacing 35%-40% of wheat flour (17% of the formula).

White industrial-grade flour is a coarse powder made from peeled chips, sun-dried on concrete, and hammer-milled. It is used as pellet binder in shrimp feed.

White table flour is a very fine white powder obtained from peeled roots that have been treated, chipped, tray-dried, and sieved through a no. 60 mesh screen under hygienic conditions. It is suitable for human consumption, used to partially replace wheat flour in cones for ice cream (25%-30%) and in noodles (10%).

First-grade industrial starch is a very fine, very white powder obtained from peeled cassava roots that have been rasped, washed, sedimented, and sun-dried on concrete. It is used as pellet binder in balanced shrimp feeds, and in cardboard boxes, replacing maize starch by as much as 100%.

Second-grade industrial starch is of lower quality than first-grade starch, because the protein fraction remains. It is used in balanced shrimp feeds and cardboard boxes, replacing maize starch by as much as 100%.

Starch for human consumption is a very fine white powder obtained from peeled roots that have been rasped, washed, sedimented, and dried on paper under hygienic conditions. It is used in bread, milk products, bakery products, and sausages.

Ground bagasse is a coarse, white-yellow powder that is a byproduct of starch extraction. It is used as a carbohydrate source in balanced feeds, and in shrimp feed, combined with meal and starches.

White bran is a coarse white powder that is a byproduct of processing for white table flour. It is used as a fiber source in feeds for livestock and pigs.

Whole bran is a coarse, brown powder that is a byproduct of processing for sieved whole flour. It is used as a fiber source in feeds for livestock and pigs.

UATAPPY's Production and Markets

Since the program was established, UATAPPY has marketed more than 8,000 t of cassava products for different uses (Tables 3 and 4). The 50 t of cassava meal produced during the first year were sold to poultry-feed plants, replacing maize grain. Since then, both markets and products have become more diversified. Ten products are now marketed, for three to five different purposes, depending on annual negotiations (Tables 3 and 4).

Between 1986 and 1989, cassava meal was almost the only product, finding a ready use as a shrimp feed binder. Between 1989 and 1990, cassava meal for shrimp feed was still being produced, but important industries began to demand cassava flour without peel. Since then, this market has been the most important, accounting for 87% of the total volume produced.

In 1990-1991, UATAPPY's total production volume increased by 70% over that of the previous year. But the percentage of UATAPPY's total produce destined for the shrimp feed market fell from 87% to 71% as two new markets opened up: sieved whole flour for the plywood industry, and starch for the cardboard industry.

Table 3. Total amount of cassava processed (t[a]) by UATAPPY, Manabí, Ecuador, 1985-1993.

Year[b]	Assns. (no.)	Fresh roots	Flours					Starch						Total annual production of cassava products and byproducts
			Indust. meal	Indust. white	Indust. sieved meal	Sieved white human consumpt.	Bran	Indust. 1st and 2nd	Human consumpt.	Bagasse	Indust. purchase	Purchase human consumpt.	Purchase bagasse	
1985-86	2	-	50	-	-	-	-	-	-	-	-	-	-	50
1986-87	4	19	96	-	-	-	-	-	-	-	-	-	-	115
1987-88	10	28	500	-	-	-	-	11	4	-	-	-	-	543
1988-89	16	-	1,100	-	-	-	-	-	5	-	-	-	-	1,106
1989-90	16	-	304	574	-	33	-	70	10	24	-	-	-	1,015
1990-91	17	-	258	982	200	6	52	119	2	51	69	4	-	1,743
1991-92	17	-	464	304	170	-	17	20	4	12	37	5	-	1,033
1992-93	17	-	127	631	292	33	80	101	17	60	155	-	26	1,522
1993-94[c]	17	-	300	512	-	21	-	89	25	56	-	-	-	1,003
Total	17	47	3,199	3,003	662	93	149	410	67	203	261	9	26	8,129

a. Values rounded to metric tons.

b. Production estimated for the crop year 1 July-30 June.

c. Preliminary data, subject to confirmation.

SOURCE: Susan Poats, 1993, UATAPPY Socioeconomic Monitoring Survey.

Table 4. UATAPPY markets and their share of cassava products, Ecuador.

Year	Product	Volume (t)	Market	Share (%)
1985-86	Meal	50	Poultry feed	100
	Total	50		
1986-87	Meal	96	Shrimp feed	83
	Treated roots	19	Export human consumption	17
	Total	115	Shrimp feed	2
1987-88	Meal	500	Shrimp feed	92
	Treated roots	28	Export human consumption	5
	Industrial starch	11		2
	Starch human consumption	4	Bread making	1
	Total	543		
1988-89	Meal	1,100	Shrimp feed	99.5
	Starch human consumption	5	Bread making	0.5
	Total	1,105		
1989-90	White flour	574	Shrimp feed	57
	Meal	304	Shrimp feed	30
	Industrial starch	70	Shrimp feed	7
	White flour			
	Sieved flour human	33		3
	consumption	10	Bread making	1
	Starch human consumption	24	Bovine feed	2
	Bagasse	1,015		
	Total			
1990-91	White flour	982	Shrimp feed	56
	Meal	258	Shrimp feed	15
	Sieved whole flour	200	Plywood	11
	Industrial starch	188	Cardboard industry	11
	Bran	52	Bovine feed	3
	Bagasse	51	Shrimp feed	3
	Starch human consumption	6	Bread making	0.5
	Sieved white flour human	6		0.5
	consumption	1,743		
	Total			
1991-92	Meal	464	Shrimp feed	45
	White flour	304	Shrimp feed	29
	Industrial starch	57	Shrimp feed	5
	Sieved whole flour	170	Plywood	17
	Bran	17	Bovine feed	2
	Bagasse	12	Bovine feed	1
	Starch human consumption	9	Bread making	1
	Total	1,033		
1992-93	White flour	631	Export to Colombia	42
	Industrial starch	292	Export to Colombia	19
	Sieved whole flour	256	Plywood	17
	Meal	127		8
	Bagasse	86		6
	Bran	80	Bovine feed	5
	Sieved white flour human	33	Ice-cream cones	2
	consumption	17	Sausages	1
	Starch human consumption	1,522		
	Total			

SOURCE: UATAPPY, 1993, personal communication.

In 1992-1993, the Colombian market was the main client: 600 t of white flour and 200 t of second-grade starch were exported. Although their use has not yet been confirmed, they appear to have been used to make adhesives.

Constraints to Commercializing Cassava Products

The major constraints are:

(1) Poor product quality, resulting from contamination at one or more of the processing stages (most important in relation to the more profitable, but more demanding, markets).
(2) Seasonality of supply (UATAPPY can only produce during the 8 "summer" months as the cassava is sun-dried).
(3) Competition from other raw materials, especially maize starch that enters Ecuador from Colombia at low prices (Table 1).
(4) Lack of knowledge: industries do not yet know how to substitute wheat flour or maize starch with cassava products.

Conclusions

(1) The current supply of cassava products is small in relation to the potential demand.
(2) Cassava products compete well in terms of quality and price with other raw materials, except for maize starch, which is cheaper imported from Colombia.
(3) "Free market" and "open border" conditions favor the commercialization of cassava products.

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CHAPTER 8

CASSAVA PRODUCTS FOR FOOD AND CHEMICAL INDUSTRIES: CHINA

*Jin Shu-Ren**

Abstract

Cassava is grown in China basically as a food security crop. But, in the last 20 years, yields have increased sharply in answer to demand from small-scale and, more recently, large-scale industries. Since the 1980s, China has seen rapid development in the commercial prospects of a wide range of cassava derivatives, including fructose-series products, sorbitol, maltol, fermentation products (such as alcohol, MSG, and citric acid), denatured starch, glucose, and glucose syrup. A hillside crop, cassava plays a key role in the economy and agroindustry of southern China. However, local economies and production in poorer rural areas urgently need modernizing if they are to fully benefit from these new developments. Recommendations are made regarding appropriate scale and technology, given the various constraints (e.g., transportation through hilly terrain and seasonal availability of fresh roots). Relevant economic factors are also reviewed. Through improved cultivars and farming practices, cassava yields can increase significantly. But, to encourage production, the value of cassava must also increase—most effectively by developing the range of its products through adopting and expanding secondary processing techniques.

Changes in Cassava Processing

During the 1960s

Cassava processing in China was mainly small-scale: production groups of 20-30 families in rural areas would plant cassava in unused areas or on sloping land as insurance for food scarcity. Because such land was usually of low fertility and received no fertilizer, cassava yields were low: in the 1960s, in Guangxi, China's largest cassava-producing area, the average yield per *mu* (1 *mu* = 665 m^2 or 15 *mu* = 1 ha), expressed as dried chips, was only 46 kg, that is, about 0.7 t/ha. The area planted to cassava varied from year to year: in 1967, in Guangxi, cassava was grown on 1,054,000 *mu*. Because of climatic constraints, cassava is a seasonal crop, and the small-scale processing plants operated only 3 to 4 months a year. The major product was poor quality starch.

Cassava was processed by first crushing fresh roots in a grinder and allowing the resulting mash to settle in

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water. The starchy mass was then strained through a fine-mesh cloth bag to separate the starch, which was then sun-dried and pulverized.

Some high-quality starch was also produced, although outputs were low. Fresh roots were crushed in a grinder; passed through a second, finer, grinder, and then through a vibrating, or octagonal, sieve that removed coarse residues; and, finally, passed to an open-ended, horizontal-flow, sedimentation trough that was 30-50 m long, 35 cm deep, and 40 cm wide. High-density impurities, such as sand and gravel, were deposited first, starch farther toward the middle of the trough, and low-density impurities, such as fiber and protein, at the far end, or flushed out. The starch was then removed from the trough, dewatered by centrifugation, dried, and pulverized. If desired, a bleaching agent, such as potassium chlorate or hypochlorite, was added before the starch entered the trough.

Starch was produced from fresh cassava for only 3 to 4 months a year. During the rest of the year, dried cassava chips were used, requiring an additional 1 to 2 days of immersion in water (or longer in cold weather) before filtering. During fine grinding, an additive would be introduced to improve the starch extraction rate.

Most of the cassava not used for starch extraction was used as pig feed. The roots were first peeled, soaked in water to remove hydrocyanic acid, and then boiled.

During the 1970s

The technology of producing quality cassava starch improved. The wooden lining of the trough was replaced by marble or glass, the centrifuge assumed a horizontal rather than vertical structure, and a crank sieve replaced the octagonal sieve. Production capacity of some factories reached 10 t/day. Guangxi had more than 270 starch factories, although the total output was low—probably less than 80,000 t, or less than 300 t/factory.

During the 1980s

Cassava production improved markedly, because:

(1) More land was made available in rural areas;
(2) Farmers were allowed to plant high-value crops, leading to major increases in the area planted to cassava;
(3) As the production of other crops improved, cassava's role shifted away from being a food security crop to providing raw material for animal feed and industry;
(4) As the national economy developed, the demand for starch increased; and
(5) Capital and imported equipment were made more readily available.

The combination of these factors created an unprecedented expansion in the scale and technology of cassava production.

The last five years

The two main cassava-producing areas in southern China now have several large-scale starch factories. By 1992, at least 10 factories had an output capacity of 40 t/day, the largest capable of producing 60 to 80 t. Overall, the factories produced more than 30,000 t. Three types of factories co-exist:

(1) Plants newly constructed or adapted, and using domestic technology. Features include a roller cleaner, two-stage crusher, countercurrent-washer, rapid blancher, whirlpool sand remover, dish-separator, dewatering

centrifuge (sometimes imported), and two-stage forced-air drier. Product quality and cost efficiency are adequate. Such factories account for 25% of cassava starch produced in China.

(2) Plants where equipment and technology are entirely imported, for example, from Japan, Germany, and Thailand. Features include a needle grinder, high-pressure crank sieve, whirlflow separator, centrifugal layer-separator, water remover, and airflow drier. Although they produce high-quality starch, such plants are economically less viable because of high equipment costs and associated steep depreciation. In addition, they compare unfavorably in performance when dried cassava chips are used in seasons when fresh roots are unavailable.

(3) Small-scale, low-technology factories that, technologically and economically, compare poorly with (1) and (2). The average starch-extraction rate is estimated as being 20% lower. Because these factories currently account for about half of southern China's annual starch production, their technology urgently needs modernizing.

With fresh cassava available for only 3 to 4 months a year, the use of dried chips has been inevitable, even though costs are higher, the starch of poorer quality, and the recovery rate lower. To counter these problems, a technology has been recently adopted that would produce "high starch, high extraction, and high storage." It involves bulk-buying fresh cassava when starch content is at its highest, and crudely processing the roots into a "paste pool." The starch can therefore be extracted in due course, extending the annual period of cost-effective, optimal quality starch production from 3 to 5 months.

By 1992, cassava starch production in southern China accounted for 23% of the national production. Cassava yields had increased notably, the regional total exceeding 1,200,000 t of dried chips. Yield per *mu* increased to 500 kg for fresh cassava and 200 kg for dried chips.

Secondary processing

Since the 1980s, the Government has shown more interest in developing cassava products derived from secondary processing. Cassava development and utilization are listed among the key projects of the sixth 5-year plan drawn up by the State Science and Technology Commission. Several national centers are also involved in the development and utilization of cassava, including the Guangxi Nanning Cassava Technical Development Center (GNCTDC).

Developing Cassava Products for Food and Chemical Industries

Industries began using cassava-based products, developed from secondary processing, during the 1980s. These include:

Fructose-series products

Fructose emerged in the 1970s as a healthier alternative to sucrose. Technology using starch as a raw material was developed soon after, and 1980 saw the first factory, with an annual fructose output capacity of 10,000 t, set up in central China. The technology of "third-generation" fructose (i.e., fructose containing not more than 10% glucose) has since been mastered in China. Through a collaborative project, the GNCTDC finished testing a pilot plant in 1986, and, in 1992, set up the first industrial plant to produce crystalline fructose. Third-generation fructose is used medically, in cases of glucose contraindication. Clinical tests on 100 diabetic patients given 25-50 g of high or crystalline fructose showed no significant changes in blood sugar level. Thus, its safety, sweetness, pleasant taste, and few calories make fructose particularly suitable for diabetics.

Chemico-industrial products

Sorbitol. A hexan-hexol, sorbitol is made from glucose by hydrogenization in a high-pressure reactor. Because it readily absorbs moisture, it can replace glycerine in the manufacture of toothpaste, cosmetics, and oil-based paints. It serves as raw material in the manufacture of vitamin C by fermentation, first into hygric acid and then into ascorbic acid. Every ton of ascorbic acid produced requires 2.7 t of sorbitol. More than 10 sorbitol factories operate in China, the largest of which has an annual production capacity of 13,000 t. A unit capable of 30,000 t is being planned, while some have recently begun using continuous-hydrogenization technology.

Production of solid sorbitol (3,000 t/year) has been successfully established in Nanning, Guangxi. Glucose produced from cassava chips is hydrogenized under high pressure (continuous process) to produce liquid sorbitol. The liquid is concentrated to 98 Brix, seed crystals are introduced, and the sorbitol spray-dried and crystallized. Solid sorbitol is easier to transport and store.

Mannitol. Another hexan-hexol, but with little moisture-absorption capacity, mannitol is usually a byproduct of iodine extraction from kelp. But it can also be produced commercially by hydrogenizing fructose, of which 50% converts into mannitol, which is then purified by crystallization. Mannitol is used medically in blood-vessel diastolic preparations, as a dehydrating agent, and in the treatment of cerebral thrombosis and other circulatory disorders. In industry, it can be used as raw material for the production of polyester, polyethylene, and solid-foam plastics.

Maltol. A sugar alcohol, maltol is produced by incomplete hydrolysis of starch, using the enzyme maltase, and subsequent hydrogenization. It is a syrup that is as sweet as sucrose, and is used in confectionery.

Fermented products

Fermented cassava products form a sizeable industry in China, and include alcohol, monosodium glutamate (MSG), and citric acid. Cassava wine was produced in the 1960s when grain was scarce, but has now become obsolete because of poor quality.

Alcohol. After 2 days of fermenting, the alcohol content in cassava can reach 10%-11%. Most factories were established in the 1970s and have an annual output capacity of 10,000 t. New factories with a 30 to 50-thousand-ton capacity are now being planned. Sugarcane and cassava growing areas usually coincide and cassava alcohol is almost always produced by sugar mills, which use molasses during the sugarcane season (November-April) and, using the same equipment, cassava roots for the rest of the year. Because cassava is low in protein and nutrients needed for growing yeast (the fermentative agent), it must be supplemented. A mixture of cassava and molasses is often used to good effect.

MSG. Also known as gourmet powder, MSG is a popular flavor enhancer in Chinese cuisine. National production exceeds 200,000 t/year. Of these, about 25,000 t are obtained from cassava starch, which first undergoes acid hydrolysis, and is then supplemented with growth factors and left to ferment for 4 or 5 days. During this time, ammonia salt is added continuously. When the glutamic acid content reaches 7%-8%, the mixture is filtered and the acid precipitated by iso-electric points. The acid is then purified by ion exchange, neutralized to produce the sodium salt, and crystallized.

Citric acid. In China, citric acid is mainly produced by fermenting sweetpotato. In 1990, more than 80,000 t were produced. Recently, however, citric acid is increasingly being produced from molasses and cassava, using an *Aspergillus* strain, known as Citrobacter, which was developed by the Shanghai Industrial Microbiology Research Institute. Cassava starch liquefies easily to a low-density liquid and, after a 4-day fermentation, the citric acid content exceeds 15%. An extraction rate of more than 92% is possible. The short fermentation period, and ease of liquefying the starch and extracting the acid keep production costs low.

Denatured starch

Since the 1980s, research on denatured starch has developed rapidly, allowing some processes to become industrialized. The current annual yield of denatured cassava starch is about 7,000 t, and includes acid-denatured starch, α-starch, ethylic starch, phosphate ester starch, and co-polymerized starch. Although current outputs are low, the future prospects of this industry are promising.

Glucose and glucose syrup

Crystalline glucose in southern China is produced primarily from cassava starch, as are injection glucose (used in medicine) and glucose syrup (DE42) (confectionery). More than 100,000 t are produced annually.

Market for Cassava Products

While the Government does not restrict sales within China, it controls exports. Fresh cassava or dried cassava chips are sold to domestic markets by farmers or by local supply-and-marketing cooperatives. The higher value chips are cut 0.5 to 1.0 cm thick, peeled, and sun-dried. The price of fresh cassava sold to factories varies according to season, starch content, and transportation distances. More recently, prices have been affected significantly by grain prices. Cassava starch costs 10%-15% less in winter, the production season, than at other times, reflecting the fact that most factories are small-scale and lack capital.

In total, about 500,000 t of cassava (based on dried chips) are used in starch production, 80% from fresh roots and 20% from dried chips. The glucose industry uses the largest amount of starch (55%), followed by MSG production (20%), family consumption (4%), and sales to northern China or abroad (11%).

Only about 15% of the cassava grown is used for alcohol and other products. Alcohol producers in cassava-producing areas have access to, and prefer, molasses from sugarcane. In northern China transportation difficulties constrain alcohol producers from buying cassava.

Citric acid production accounts for about 3% of cassava grown.

About 600,000 t of dried cassava chips are exported annually, but much is used locally as animal feed, both in traditional form and, more recently, in compound feeds.

Although yields increased sharply in the 1980s, processing remained backward and markets were few. More recently, however, the processing industry has been modernizing and supply and demand have increased in tandem.

Opportunity and Competition

The development of cassava production and processing in China, already inhibited by strong domestic grain production, is further restricted by the natural coupling of major cassava and sugarcane producing areas. Thus, market prices of sugarcane largely dictate the extent of cassava farming. Furthermore, where sugarcane yields are high, markets stable, and farmers experienced producers of sugarcane, cassava is unlikely to be planted in preference. However, where land is less fertile and cane yields low, cassava's potentially higher production is more attractive.

Although its starch is used as an additive in cooking, cassava is rarely used as a food in China. Most cassava is destined for the textile, paper making, and chemical industries, where it must face competition from maize products.

Cassava's future prospects are good, even though production yields are still low: about 500 kg of fresh roots per *mu* (or 200 kg per *mu* of dried chips). Although most farmers still use an old variety, Nanyang Red, fresh cassava yields may eventually reach 2 or 3 t per *mu* with the adaptation of imported improved varieties. That is, improved technology would increase the current average yield per unit area by an estimated 500%.

The rapid development of industry in China provides an ideal opportunity for cassava. Yields of starch increased five-fold between 1981 and 1989 as the annual growth rate exceeded 15%. Those industries using starch as a raw material, such as MSG, maltol, glucose, and fructose, anticipate rapid expansion while the domestic market remains unsaturated. Because maize-growing areas are far from cassava-producing areas, cassava has the advantage of lower transportation costs. While the price differential is maintained, cassava has the advantage in southern China.

The market for cassava products is potentially rich, particularly for denatured starch, which is still new. Although the use of cassava starch in foodstuffs is currently limited, its future potential is high.

Conclusions and Suggestions

Cassava, a hillside crop, plays a key role in the economy and agroindustry of southern China. Cassava products are important both in their own right and as industrial raw material. Their future development is integral to that of the economy of rural and poorer areas. Two objectives should be pursued in parallel: to increase yields, and to raise the value of cassava. For the first, emphasis must be given to importing and adapting improved varieties, developing farming technology, and improving fertilizers. The second objective requires commitment to developing cassava products such as those discussed above. If cassava is processed only at the primary level and commands only basic prices, then its prospects are severely limited. Governmental policy in this area must therefore promote research into secondary processing techniques to accompany the improvement of cassava cultivars.

The modern cassava starch factory, in scale and in the technology employed, should correspond closely to local needs and to take account of such factors as transportation difficulties, and seasonal variations in production and availability of fresh roots. The small, largely undeveloped factories of southern China urgently need modernization. At present, Chinese-manufactured machinery is adequate for such factories, whereas investment in expensive machinery from developed countries can increase production costs out of proportion to benefits in output and quality. Secondary processing of cassava does not need a high degree of automation nor large factories (which are penalized by higher transport costs), and is readily adaptable to local rural conditions.

Most cassava industrial activity in China has so far been related to high-value products, such as MSG and sorbitol, and, although progress is evident in some areas, effort is required in others, especially in the development of denatured starch. Given realistic processing and technological transformations, cassava has much to offer the farmers and local economies of southern China.

Chapter 9

Thai Cassava Starch Industry: Its Current Status and Potential Future[1]

*Boonjit Titapiwatanakun**

A Brief History

Early development

Cassava first came as a subsistence crop, probably to southern Thailand, through Malaysia, from West Java in Indonesia. Industrial cassava processing began in the 1920s in Chonburi Province, on the Eastern Seaboard. The first plants used a simple sedimentation process to extract starch, which was destined mostly for household consumption. At the end of World War II, starch milling was introduced, thus catalyzing the development of Thailand's now modern cassava starch industry. Most of the starch was exported, together with certain byproducts.

In the early 1950s, starch was cassava's most important export product. In 1955, for example, 54,122 t of cassava products were exported, with a total value of 69.1 million baht. Of this value, cassava starch accounted for about 76% (i.e., 54% of the tonnage) and byproducts about 22% (i.e., 44% of tonnage). Most of the starch was exported to USA and Japan, and the byproducts to Malaysia and Singapore. Cassava starch exports increased every year from about 29,000 t in 1955, peaking at 227,000 t in 1961, and dropping slightly in 1973.

No published data are available on domestic cassava starch consumption, but it was probably less than the amount exported, indicating a highly export-oriented industry that developed in response to export markets.

Entering the animal feed market

The value of cassava starch exports increased to 220 and 223 million baht in 1960 and 1965, respectively, but, as exports of cassava products for animal feed expanded rapidly, their percentage share of the total value of cassava exports decreased from 76% in 1960 to 33% in 1965.

Thailand began processing cassava for animal feed in the late 1950s in response to heavy demand (triggered off by the Common Agriculture Policy) for nongrain feed ingredients (NGFI)—including cassava products—from the then European Economic Community (EEC, now the European Union). In 1957, cassava byproduct exports to the Netherlands

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1. No abstract was provided by the author.

and the then West Germany were 1,400 and 7,000 t, respectively.

At first (1955-1968), Thailand exported, as animal feed ingredients, cassava byproducts, meal, and chips; during 1969-1982, native or soft pellets were exported; then from 1983 to the present, hard pellets. These products evolved as efforts were made to minimize transport costs and contamination during loading and unloading. Such evolution reflects the increasing efficiency of the industry's marketing system, stimulated by coordination with, and technological transfer from, importing countries.

Exporting cassava products for animal feed had a significant socioeconomic impact on Thailand, for example, farm income, employment, and foreign exchange earnings all increased. The area planted to cassava increased dramatically from 38,400 ha in 1957 to 171,000 ha, producing 2.6 million tons, in 1968. Although about 75% of the expanded area first occurred in Thailand's eastern region, by 1977, the northeast was producing more than 50% of the national production. The starch industry also benefited, setting up plants in the new areas.

The increased export trade also encouraged the development of equipment that enabled high-speed loading of pellets, and permitted specialization within the export business. Thai exporters could set up trading companies in the EEC, thus opening up investment opportunities in the industry.

In July 1982, however, the EEC, through a Cooperation Agreement with the Kingdom of Thailand on cassava production, marketing, and trade, set an annual maximum of 5 million tons of imports of Thai cassava products as animal feed. The Agreement slowed down the industry's development, and created the need to explore new ways of using the cassava root and its products, particularly as starch.

Modified starch

Even with Bangkok as a significant market, Thailand was already exporting native starch to USA and Japan, who processed some of it into the more valuable modified starch. In Thailand, the earliest processing of native starch into modified starch (glucose syrup) was in 1950, followed by monosodium glutamate (MSG) in 1960. In the late 1970s, USA and Thailand collaborated to produce modified starch for export, followed by joint ventures with European and Japanese firms. At the same time, exporters of cassava for animal feed integrated with native and modified starch processing enterprises.

When modified-starch processing began in Thailand, it was typically a closed industry, but with the need for new export products, the industry opened up to the extent that even plants in cassava-producing areas are producing modified starch, using simple processing techniques. Plants using more complex techniques to produce chemically modified starch are located mostly in the provinces around Bangkok, where most industries that use modified starch are located. Seventeen modified-starch plants, with an estimated total capacity of 300,000 t/year, were operating in 1990, producing about 250,000 t.

The Thai modified-starch industry developed rapidly during the last decade, because, first, the international trade in native starch was hampered by import barriers, imposed to protect domestic native starch industries. In contrast, few import barriers operated against modified starch. Second, Thailand's impressive economic growth during 1980-1990 made possible the investment in high-level technology for processing. Third, modified starch provided an outlet for the foreseeable overproduction of cassava, caused by the EEC's restricted imports of cassava pellets.

Production, Marketing, and Price Formation

Root and starch production

During the past decade, data from the Ministry of Agriculture and Cooperatives (MOAC) showed that total cassava root production increased from 19 million tons in 1983 to about 20 million tons in 1992, that is, at an annual growth rate of only 0.7%. Yield per ha decreased from about 18 t in 1983 to 14 t in 1992, mainly because fertilizers were not applied in most cassava-growing areas, especially in the northeast.

The national average production costs per ton of cassava increased from 450 baht in 1989/90 to 470 in 1990/91 and 540 in 1991/92. The national average farmgate price per ton (i.e., the price received by cassava growers) was 620 baht in 1990, 830 in 1991, and 770 in 1992. Between 1990-1992, the average farmgate price increased by 24%, which compares with a production cost increase of 20% during the same period. Cassava farmers made, on the average, a profit of 253 baht/t. But if production costs continue to increase at their current annual growth rate of 7%, the competitiveness of Thai cassava products in the future world market will be jeopardized.

During the last 5 years, about 14-15 million tons of root were processed into animal feed products (chips and pellets), which were mostly exported, and 5-6 million tons were processed into cassava starch.

Statistics on starch production are not available, although the Thai Tapioca Flour Industries Trade Association (TTFITA) estimates that the total cassava or native starch production was about 1.2 million tons in 1989, 1.3 million in 1990, and 1.4 million in 1992.

As for many agroindustries, the total number and capacity of cassava starch plants are not updated by official sources. Official records, especially those of the Ministry of Industry (MOI), register data as plants are established, but conduct few surveys for updating. For example, MOAC reported the total number of starch plants in 1970 as 50 and in 1973 as 128. The MOI then reported 146 plants in 1978, but, in 1987, only 82, with an estimated capacity of 1.5 million tons. Although, in 1990, the number dropped further to 45 plants—a decrease of 45% (Table 1)—the estimated capacity dropped only 13% to 1.3 million tons.

The starch industry may have suffered from overcapacity since 1978. Even in 1990, the industry operated for only 8 months. If the industry were to operate 10 or 11 months/year, then its potential production would be 1.7-1.9 million tons of starch. The capacity of some plants could be expanded, especially in the eastern and northeastern regions.

During 1978-1990, the number of starch plants in the eastern region decreased dramatically from 121 to 17, whereas in the northeast it increased from 12 to 22, suggesting a shift of cassava-producing regions from eastern to northeastern Thailand, as the animal feed market expanded.

Table 1. Number of cassava starch plants and production[a] by region, Thailand, 1989 and 1990.

Region	1989		1990	
	Plants (no.)	Production (1,000 t)	Plants (no.)	Production (1,000 t)
Northern	4	39	4	39
Western	2	27	2	27
Eastern	18	263	17	263
Northeastern	23	936	22	1,024
Total	47	1,265	45	1,353

a. Annual production figures were estimated by multiplying the daily capacity of plants by 240 days.

SOURCE: TTFITA, various years.

But plant numbers may have dropped as the many small, family-operated businesses, using old and mixed technologies, lost out in the competition with modern plants, which had comparatively higher production efficiency. Most modern starch plants were constructed by local firms, and more than 80% of the materials and machinery used for construction were locally produced and assembled. Thai firms even built starch plants in Indonesia.

Marketing and price formation

The marketing of cassava roots is simple: through local truckers to both chip-and-pellet and starch plants. Because the Government allocated quotas of exports to the EEC, based on accumulated stock in 1988, the price of roots was determined by that of chips and pellets during the time exporters were accumulating their stock and before stock checking. Once stock checking was over, root prices were more or less determined by native starch prices. When domestic prices of starch were high, following high world prices, then only those roots that could not meet starch content requirements would be sold to the chip-and-pellet plants. In other words, roots are sold first to the starch plants, until their demand is satiated, and then to chip-and-pellet plants.

Two major outlets are available for native starch: (1) domestic consumption, and (2) export. Domestic consumption includes foodstuffs and industrial use (discussed below), but also raw material for domestic modified-starch plants located in provinces around Bangkok. Their products, however, are mostly exported. Native starch is sometimes sold as wet starch to modified-starch plants located in cassava-producing regions.

In terms of market share, starch has been more or less equally divided between export and domestic consumption for the last 5 years. But prices of domestic native starch are strongly influenced by export markets for both native and modified starch. Prices in importing countries compete with prices of other starches, especially maize, and the eventual prices reached, in turn, influence Thai domestic prices.

In the domestic market, native starch is, comparatively, the cheapest starch available and used at costs that comprise a relatively small percentage of the value of the final products. This enables domestic industries that use native starch to absorb price fluctuations without seriously affecting the price of the final product.

The links among prices for modified starch, native starch, and roots are shown in the following list of 1990 average prices, and marketing and processing costs, obtained from a 1991 industry survey:

Items	US$/t[a]
Modified starch price c.i.f., Japan	405.0
Freight and insurance costs, Thailand-Japan	45.0
Modified starch price f.o.b., Bangkok	360.0
Exporting costs	20.0
Modified starch prices at plant, Bangkok	340.0
Processing costs of modified starch, including 5% weight loss	117.8
Native starch prices at Bangkok plant	222.2
Transport costs, Nakhon-Ratchasima and Bangkok	9.0
Native starch prices at plant in Nakhon-Ratchasima	213.2
Processing costs of native starch (conversion rate of starch to root = 1:5)	52.0
Value of roots per ton of starch at plant	161.2
Value of wastes (10% of the value of roots)	16.1
Total value of roots per ton of starch at plant	177.3
Price of roots per ton (root prices at the plant in Nakhon-Ratchasima)	35.5
Production costs of roots in 1989/90 (published by MOAC)	17.6

a. Exchange rate is 25.50 baht = US$1.00 (1994).

The above list also shows the relationships between Bangkok prices and Nakhon-Ratchasima Province prices for native starch and roots. Under normal conditions, cassava starch plants derive their daily buying price of cassava roots from this type of information.

Current and Future Domestic Use and Export

Domestic use

Overall, domestic use of cassava starch can be classified into either food or nonfood industries. No official records are available of the total cassava starch consumption by both groups. In 1991, an industrial survey was conducted by the Thailand Development Research Institute Foundation (TDRI) to compile and estimate starch consumption for that year, and to project future use.

Starch consumption was estimated by calculating the percentage of starch consumption per unit of final product, whether food or nonfood. The total starch consumption of each final product was then computed by multiplying the percentage use by the total annual production of each final product. The annual total cassava-starch consumption for producing the final products was obtained during the survey as a discrete series. The complete series was then constructed by using growth rates between periods.

Once the series of starch consumption data was constructed, the future consumption of starch of each product was forecast by a simple demand projection equation:

$$D = R + NY \qquad (1)$$

where:

D = growth rate of quantity demanded for the final product

R = growth rate of population (the annual population growth rate, estimated by the TDRI as 1.3%, for 1991 to 2001 was used)

N = income elasticity of demand for starch for the final product (using the 1972 per capita income as the base year)
Y = growth rate of income per capita, using 1972 as the base year (the TDRI projection of 6.4% for 1991 to 2001 was used)

The estimate of starch consumption for each final product is discussed below:

Food industries

Monosodium glutamate and lysine. In 1991, three MSG plants operated: Ajinomoto, Raja, and Thai Churos. In 1960, Ajinomoto set up the first MSG plant in Thailand and was the first to use modern technology to modify cassava starch. Ajinomoto is also the only MSG plant to use cassava starch as the major raw material, which it does at a rate of 2.4 t of starch per ton of MSG. The other two plants use molasses.

In 1986, the Ajinomoto group set up the first and only lysine plant, not just in Thailand, but also in Southeast Asia. To produce lysine, the plant consumes cassava starch at the same rate as for MSG.

To produce both MSG and lysine, the Ajinomoto group consumed 28,000 t of cassava starch in 1980; 33,000 t in 1985; and 87,000 t in 1990. Growth rates were 3.3% during 1980-1985, and 21.4% during 1985-1990. Based on these data, a statistical series of starch consumption data for MSG and lysine production during 1980-1990 was constructed. These data were used to estimate the income elasticity of demand for starch for MSG production, that is, 1.75. The estimation equation, of which the autocorrelation was corrected, was as follows:

$$1n(STl) = -16.043 + 1.749\ 1n(GDP) \qquad (2)$$
$$(-9.125) \qquad (9.034)$$
$$R^2 = 0.950$$
$$D.W. = 1.244$$

where:

STl = per capita demand for starch in producing MSG and lysine
GDP = per capita income in the 1972 base year

The growth of demand for starch to produce MSG and lysine can be approximated by equation (1). That is, if D = 12.617% (or 1.33 + 1.75 x 6.45), then starch consumption for producing MSG and lysine in 1991 = 97,977 t (87,000 x 1.12617).

Sweeteners (excluding fructose). Domestic production of glucose syrup began in 1950, glucose powder in 1976, and sorbitol in 1980. The conversion ratio of each product and the estimated annual production obtained from the survey are as follows:

Product	Ratio of cassava starch to product	Estimated annual production of final product (tons)
Glucose syrup	1:0.92	30,000
Sorbitol	1:1.20	28,000

The glucose syrup producers estimated that sweetener production consumed 28,040 t of cassava starch in 1950; 42,060 t in 1980; and 70,100 t in 1990. Based on these data, a statistical series of cassava starch consumption data was constructed, and the income elasticity of demand for starch was estimated at 1.16. The annual growth rate of demand for sweeteners was calculated at 8.812%, which was used to project demand for cassava starch for producing sweeteners (but not fructose), during 1991-2001.

Pearl sago. Pearl sago or tapioca was produced by many small, and a few large, cassava starch plants. In 1990, the TTFITA listed 12 pearl-sago plants, five of which were large. But many small, family-operated plants may not have been counted. Processing involves mixing cassava starch with water, pearling the mixture, and sun-drying it. The conversion rate of cassava starch to pearl sago is 1:0.9. Starch consumption was about 23,000 t in 1986 and 30,000 t in 1990, an annual growth rate of 6.7%. Pearl-sago producers expect that the rate will be maintained for the future, because both domestic and export markets are expanding. The 6.7% growth rate was therefore used to project cassava starch consumption in pearl-sago processing.

Household consumption. Three kinds of starch are consumed by the household: rice starch, sticky rice starch, and cassava starch. Total starch consumption was reported at 7.12 kg/person per year. Assuming equal proportions of starch consumption, then per capita cassava starch consumption would be 2.37 kg. A statistical series of household starch consumption data was constructed for 1991-2001 by assuming a constant per capita consumption at 2.37 kg and using the TDRI's population projection. The constant was approximated from a household survey conducted by the Office of Agricultural Economics, MOAC, during 1970-1971.

Other food industries. Cassava starch is used as a raw material or ingredient by canning and other food industries that make, for example, instant noodles, vermicelli, sauces, soups, sausages, and candies. The annual cassava starch consumption was estimated to be 17,960 t in 1980 and 31,986 t in 1990. Based on these data, the income elasticity of demand for starch was calculated at 0.64. Equation (1) was used to project future starch consumption.

Nonfood industries

Paper industry. In 1989, the Thai Pulp and Paper Industries Association (TPPIA) reported that 38 paper mills were operating, 12 of which received the Board of Investment (BOI) privilege. The total annual capacity was 870,000 t of paper, proportioned as follows: 521,000 t in kraft paper; 193,000 in printing and writing paper; 110,000 in paperboard; and 46,000 in sanitary paper. Although Thailand imports newsprint, by the end of 1993, three plants with total annual capacity of 300,000 t were operating.

Of these five types of paper, only the plants producing kraft paper, printing and writing paper, and paperboard used cassava starch as a raw material in production. The average consumption rate of starch was about 5% of the total paper weight, with paper production expanding at a rate of 13% per year. From these data, cassava starch consumption in the paper industry was estimated at about 42,000 t in 1990, and projected by using a 13% annual growth rate.

Plywood industry. In 1990, 35 plywood manufacturers were operating. One piece of plywood uses about 370 g of cassava starch. As far as can be ascertained, the average metric ton of plywood contains 80 pieces. Total plywood production tends to be underreported because logs are imported illegally from neighboring countries. More accurate estimates may be obtained by examining the relatively constant plywood market share of the Thai Plywood Company Limited, a state enterprise, which share held at 10% during the last few years. Estimates for cassava starch consumption were 4,775 t in 1989, 6,924 in 1990, and 6,700 in 1991.

For the next 3 years, the annual cassava starch consumption in the plywood industry may stay at about 6,700 t, because, first, importing logs from neighboring countries will become difficult as these countries establish their own plywood industries and the prices of logs rise. Second, other boards are substituting plywood, such as hardboard, medium board, medium density fiber board (MDF), and soft board. Some of these products are made from sugar fiber. Third, the comparative advantage in plywood production of Thailand will decrease over the years as that of Indonesia and Malaysia increase. Fourth, some plants are replacing cassava starch with phenolic resin, which provides a better adhesive quality. Total cassava starch consumption in the plywood industry will therefore decrease by 30%-40% from the 1993 level and then remain stable until year 2000.

Textile industry. Cassava starch is applied to the yarn in the warp before weaving, at about 1% of the warp's total weight. Modified starch is also used in dyeing, an industry that is not yet well developed in Thailand. The estimated current consumption of cassava starch in the textile industry is therefore minimal. A statistical series on cassava starch consumption data was constructed for 1985-1990, and used to estimate a simple trend regression. The simple trend equation is as follows:

$$STH = 9657.5 + 816.5\,Y \qquad (3)$$

t-vale = (26.699) (6.182)

$R^2 = 0.9508$

D.W. = 2.0012

where:

STH = total annual cassava starch consumption

Y = year 1985 = 1

Other industries. Other industries that use cassava starch as a raw material are those that manufacture glues, paper products, and chemicals. The estimated cassava starch consumption are about 15,000 t in 1980, and 60,000 t in

Table 2. Projected consumption of cassava starch by Thai food and nonfood industries.[a]

Industry	1991	1996	2001
Food-processing industries	**375,071 (73)**	**516,463 (70)**	**772,819 (65)**
MSG and lysine	97,977 (19)	170,456 (23)	322,194 (27)
Glucose syrup	76,375 (15)	113,368 (15)	177,490 (15)
Pearl sago	32,060 (6)	44,690 (6)	62,295 (5)
Household consumption	134,908 (26)	144,582 (19)	153,645 (13)
Other food industries	33,751 (7)	43,367 (6)	57,195 (5)
Nonfood industry	**136,151 (26)**	**226,357 (30)**	**411,634 (35)**
Paper	47,098 (9)	86,776 (12)	159,879 (13)
Plywood	6,700 (1)	2,010 (<1)	2,010 (<1)
Textiles	14,557 (3)	18,640 (3)	22,722 (2)
Other industries	67,796 (13)	118,931 (16)	227,023 (19)
Total	**511,221 (100)**	**742,818 (100)**	**1,184,453 (100)**

a. Figures in parentheses are rounded percentages of the total.

SOURCE: TDRI, 1992.

1990, indicating an annual growth rate of about 15%. This growth rate was used to project future consumption of cassava starch.

Estimates of cassava starch consumption in Thailand are presented in Table 2. In 1991, about 511,221 t of cassava starch was consumed, 73% of which was consumed by food industries and households. When the data are broken down, household consumption is highest with 26%, followed by MSG and lysine (19%), sweeteners (excluding fructose) (15%), "other food industries" (7%), and pearl sago (6%).

Nonfood industries consumed 136,151 t of cassava starch or 26% of the total. "Other nonfood industries" consumed the highest percentage (13%), followed by paper industries (9%), textile industries (3%), and plywood industries (1%).

The estimated total domestic starch consumption in 2001 is 1.18 million tons. Although starch consumption by nonfood industries will have increased to more than 400,000 t (35% of the total), most domestic starch consumption will still be in the food industries (65%). Among the industries, the MSG-and-lysine industries will consume the most (27%), followed by "other nonfood industries" (19%), sweeteners (15%), and paper industries (13%).

The fructose industry used 9-15 thousand tons of cassava starch during 1988-1990. Once existing food regulations permit the use of fructose in the domestic soft drink industry, then demand for fructose will increase by about 20% per year. This will mean an extra 17,600 t of cassava starch in 1991; 38,000 in 1996; and 92,200 in 2001.

Exports and major markets

As mentioned above, export markets for Thai cassava starch strongly influence domestic price formation. The future prospects of export markets are therefore highly significant for the development of, not only the starch industry, but the entire cassava industry in Thailand.

On the whole, the starch industry has been export oriented since the 1940s. Although the quantities of exported cassava starch have fluctuated, an upward trend is obvious. Data from the TTFITA show that exports of cassava native and modified starches increased from 459,048 t in 1985 to 656,291 in 1990. Exports to Japan increased from 143,619 to 204,572 t, and to Taiwan from 124,926 to 248,434 t. That is, the export share of Japan and Taiwan increased from 58% to 69% of all exports. These countries are expected to remain major export markets in the future.

Japan. Although data from the Japanese Ministry of Agriculture show that Japan's total annual starch consumption increased from 2.4 million tons in 1986 to 2.7 million in 1990, other sources suggest that Japan consumes at least 3.5 million tons of starch annually. The Japanese Government has set 0.2 million tons as the maximum annual import quota for starch to protect the domestic starch industry, which is based on sweetpotato and white potato.

Starch in Japan is consumed mostly by manufacturing and processing industries, especially for syrup dextrose (60%). Other industries, in descending order, are chemicals (including medicines) or modified starches, fibers, foodstuffs, paper and adhesives, beverages, fish-paste products, and MSG. Sources of starches are maize (79%), white potato (10%), sweetpotato (5%), imported starch (4%), and wheat starch and/or flour (2%). Some of the products of processing are re-exported.

The manufacturing and processing industries are not only the major consumers of starch, but they are also the major importers, especially the syrup dextrose producers, modified-starch processors, re-export processing industries, and manufacturers of MSG, medicines, and adhesives.

In 1990, the average wholesale prices of starch in Japan showed that native cassava starch was the cheapest (Table 3). If there were no import barriers, cassava starch imports would increase tremendously.

Imported modified starch is subject to an 8% import duty if from developed countries. Although developing countries pay 0% tariff, they face an import ceiling, imposed by the Japanese Government since 1989. The ceiling is based on a total value per year. During the early stages of implementation, the Japanese Government was flexible, and some groups of modified starches were imported at much higher rates than the set ceiling. Imported modified cassava starch must compete with domestic modified starch made from maize.

Table 3. Average wholesale prices of starches in Japan, 1990.

Starch	Price (yen/kg)
Domestic starches produced from:	
Sweetpotato	65.00
White potato	140.00
Maize	62.00
Imported starches	
Native cassava starch	33.00
White potato starch	63.00

SOURCE: TDRI, 1992.

Thailand's competitive position in the Japanese market is determined by its status in two categories: first, the native starch market, in which Thailand still has the strong advantages of low prices and continuous supplies; and, second, the modified-starch market, in which Thailand faces not only competition from domestic modified starch, but also from modified starch imported from the EEC (which makes it from low-priced starch, itself imported from Eastern Europe). Future prospects in the Japanese market, however, depend heavily on Japan's trade protectionist policies.

Taiwan. Being a newly developed industrialized country, with a rapidly growing economy, Taiwan has had to restructure its agricultural sector. From producing basic raw materials, it now produces high-value products such as fruit and those from livestock and fishery. Consequently, Taiwan expects to import more of both raw and finished agricultural products. Although Taiwan does not impose a tariff import barrier on cassava starch, it does on imported cassava products (Table 4).

Thai cassava starch products have good prospects in Taiwan, where Thai exporters and concerned governmental agencies have actively promoted cassava products in the Taiwan market.

Projections of cassava starch exports to Japan and Taiwan, and of total exports. Simple linear trends (Table 5) were used to project cassava starch exports to Japan and Taiwan, and in total. The

Table 4. Import duties imposed on cassava products by Taiwan.

HS code	Tariff rate
0714.10 Manioc (cassava)	20%
1108.14 Manioc (cassava) starch	17% or NT$1,200/t
1903.00 Tapioca and substitutes prepared from starch	17% or NT$1,306/t
3505.00 Dextrins and other modified starches	7.5%-20%[a] 7.5%-17%[b]

a. Imposed for all countries.
b. Applied to countries with reciprocal benefits, such as Thailand.

SOURCE: TDRI, 1992.

Table 5. Projected cassava starch exports to Taiwan and Japan and total exports (in tons), Thailand, 1993-2001.

Year	Taiwan	Japan	Total exports
1993	355,673	259,837	872,614
1994	390,922	278,065	939,709
1995	426,171	296,293	1,006,805
1996	461,420	314,520	1,073,901
1997	496,668	332,748	1,208,093
1998	531,917	350,976	1,275,189
1999	567,166	369,204	1,342,285
2000	602,415	387,431	1,342,285
2001	637,664	405,659	1,409,381

SOURCE: TDRI, 1992.

projection of total starch exports, however, did not include the possibility of new markets, such as South Korea's paper industry. At present, cassava starch imports under the international HS code 1108.14 are not restricted by South Korea. Another potential market is Russia, if special export credits can be made available to Thai exports through the establishment of an export-import bank. At least 10,000 t of cassava starch would then be exported.

Based on the above estimates, demand for cassava starch in both domestic and export markets in 1996, will reach about 1.82 million tons (9.1 million tons of roots), of which domestic consumption would account for 41% (data not shown). In 2001, total demand would increase to 2.6 million tons (13 million tons of roots), of which domestic consumption would account for 46%. The future of the cassava starch industry will therefore still be export oriented.

Scenario of Future Industrial Adjustment

As mentioned earlier, the EEC's Common Agricultural Policy (CAP) triggered off the development of Thai cassava products for the animal feed industry. The EEC has been the only major market for these products, a result of the EEC's high cereal prices. Hence, any changes in the CAP will have a strong impact on the Thai cassava industry. Analyses of CAP reforms will therefore be imperative for predicting the industry's future prospects and development.

The CAP reforms

Overall, the CAP has fulfilled the EEC's objective of reaching self-sufficiency in food, but at the high price of subsidizing the agricultural sector. The CAP also created several problems, especially the overproduction of cereals, and livestock and dairy products, which cost more than ECU 79,000 million.

One reason for the overproduction of cereals was their reduced use in the animal feed industry, which substituted the highly priced cereals with cheap NGFI imports. The EEC has tried to limit and reduce NGFI imports by setting quotas for cassava imports from Thailand, Indonesia, Brazil, and China. Many other NGFI products, however, were imported without restrictions or tariffs.

As well as the problems created by the CAP, the EEC also has had to face pressure from the GATT Uruguay Round of trade negotiations to liberalize trade. CAP reforms were therefore inevitable—concentrating on decreasing agricultural subsidies to reduce grain and meat surpluses. The strongest impact on NGFI imports came from the drastic decrease of intervention prices for cereals, which severely reduced domestic wholesale prices of cereals. Three major changes from the existing system occurred:

(1) Agricultural support shifted from being solely price subsidies to being compensatory payments to producers;
(2) Measures for increasing production for self-sufficiency were no longer emphasized; and
(3) Free trade was encouraged while maintaining the basic principles and instruments of the CAP.

Under the CAP reforms, cereal prices will change as follows:

(1) Buying-in prices and intervention prices will be the same for every cereal; and
(2) From the 1993/94 season (July) onward, all cereal prices (ECU per ton) will be:

Season	Intervention price[a]	Target price[b]	Threshold price[c]
1993/94	117	130	175
1994/95	108	120	165
1995/96	100	110	155

a. The price at which the EEC is prepared to buy cereals if the market price is below it.
b. The price the EEC wants producers to receive (and consumers to pay). The EEC will intervene through import levies (taxes) or by buying surpluses to ensure that prices do not fall below the target level.
c. The price at which cereal imports enter the EEC, i.e., the world price plus the variable import levy.

Impact of CAP reforms on prices of cassava products and roots

The CAP reforms will probably strongly effect NGFI imports, especially those providing sources of energy in animal feed, such as cassava products. As cereals become cheaper, substitutes will be used less. The EEC commission reported that the substitution effect would be 6-7 million tons (EEC, 1993b).

Given the price relationship of ECU 24 per ton between wheat and cassava products used in compound feed in previous years, Thai cassava products are expected to be competitive in the EEC market and to be consumed by the animal feed industry at the current rate of about 5 million tons. Prices, however, would decline to the following levels:

Season	Wholesale prices of cassava products in the EEC (ECU per ton)
1993/94	93
1994/95	84
1995/96	76

However, the above price levels show the worst scenario. Given the exchange rate of ECU 1 = US$1.19 and US$1.00 = 25.30 baht, farmgate prices of cassava roots in Nakhon Ratchasima Province, Thailand, would be as follows:

Season	Farmgate prices in Nakhon Ratchasima Province, Thailand	
	US$/ton	baht per ton
1993/94	22.81	577.14
1994/95	18.78	475.26
1995/96	15.93	403.00

Based on MOAC statistics, the national average cost of producing cassava roots in 1991/92 was 540 baht/t (US$21.34/t). This implies that farmers received only 37.14 baht/t (US$1.47/t) in 1993/94, and that, in 1994/95 and 1995/96, farmgate prices will be less than production costs. Obviously, if these price levels become reality, cassava farmers will switch to other crops.

Also obviously, hard pellet prices in Rotterdam (ECU 76-93/t) and root prices in Nakhon Ratchasima (US$15.93-22.81/t) will discourage Thai exports to the EEC. That means the quota rent of export quota in the EEC will vanish, making it difficult for Thai exporters to export pellets to non-EEC markets at such low prices that they would obtain export quota to the EEC and thus sell pellets at high prices. In fact, current non-EEC markets for Thai pellets are subsidized by the quota rent to the EEC. These markets are not potential markets for cassava pellets, unless cereal supplies become drastically short and world prices of high-protein ingredients for animal feed (soybean meal) become very low.

Impact of CAP reforms on root supplies to the Thai cassava starch industry

This section tries, perhaps prematurely, to project what would happen if exports of Thai cassava products as animal feed to the EEC were decreased drastically. The projection is based on observations of events in Nakhon Ratchasima Province.

After the new CAP was implemented in July 1993, buying prices for roots offered by plants in the province decreased from 740 baht/t in July to 700 in October. This was a result of adjustments in the EEC's compound feed industry and of the Thai export industry to the CAP reforms, which dropped export prices for cassava products for animal feed in the EEC. Consequently, producers of cassava chips and pellets had to lower their buying prices for roots. As root prices decreased, root supplies also decreased.

The immediate impact of CAP reforms on the Thai cassava starch industry was to create competition among cassava starch plants to obtain the cheapest root supplies. This meant that, if cassava farmers delayed their harvests, root prices would increase in the short run. But, if prices of cassava products in the EEC dropped to ECU 93/t, then exports to the EEC in 1993/94 would be reduced drastically. Eventually, surpluses of cassava roots would develop and prices will drop below 700 baht/t in 1993/94.

If prices remain at 700 baht/t (or US$27.67/t), which would give a net farmgate price of 580 baht/t (US$22.92/t), farmers would find it unprofitable to grow cassava. For example, the 1993/94 root production costs in Nakhon Ratchasima were 578.50-664.80 baht/t (US$ 22.87-26.28/t). This implies that cassava root production will begin decreasing.

The Thai Department of Agriculture reported that production costs for cassava would decrease to 509.00 baht/t (US$20.12/t) if farmers followed appropriate agricultural practices and used the new Rayong 60 variety. Trade associations of Nakhon Ratchasima Province are now working closely with concerned governmental agencies to provide extension services for cassava farmers to encourage them to adopt new agricultural practices and varieties. Extension services, however, are not sufficient if farmgate prices are not high enough. To ensure their raw material supplies, therefore, cassava starch plants have begun contract farming.

To avoid cassava root surpluses, the Government had already, in early 1993, launched a program to encourage farmers to reduce planting areas (now totalling 400,000 rai, or 64,000 ha). It is still too early to assess the program's success, but cassava production will decrease in any case, if the above price level of 700 baht/t is realized for 1993/94.

Cassava starch plants will therefore face problems of root supplies, and their period of operation may become smaller than 8 months if contract farming and extension services for improved varieties and agricultural practices are not realized.

As the production of cassava products for animal feed decreases, the cassava market will become dominated by starch plants operating in cassava-producing areas. During peak seasons, local starch plants will not be able to buy all available roots. Root prices will therefore drop to levels at which chip-and-pellet plants find profitable to start their operations. Thus, a new market equilibrium of root prices will be established at levels profitable for farmers and chip-and-pellet producers. The level will depend heavily on the export prices of chips and pellets and on domestic demand for these products. Even so, both farmers and starch plants would mutually benefit from setting up a system that regulates root supplies.

Starch processing

As low prices and decreasing demand for roots force reductions in cassava production, the root marketing period will shorten and adjust to the seasonal demand for cassava products in the EEC market. Cassava starch plants would have fewer operational days and higher average production costs. To overcome such problems, the plants may either increase capacity per day, or minimize production costs wherever possible.

The first alternative may be possible by merging plants. Thus, only large and efficient starch plants will survive, and their operations would also be further integrated with high-value processing activities such as modified starch. The plants may also be forced to diversify into commodity trade.

Production costs may be minimized through joint efforts in obtaining special rates from governmental authorities for utilities such as electricity, which accounts for more than 35% of total processing costs.

Governmental policy

Although concerned governmental agencies realize that the CAP reforms will generate negative impact on the Thai cassava industry, especially for animal feed, the only policy so far implemented is that of reducing cassava planting areas. Short- and long-term policies for the cassava industry are yet to be formulated. In addition, the Government has still to decide whether to renew or renounce the Agreement, which will expire in 1994, between Thailand and the EEC on cassava exports.

Summary, Conclusions, and Recommendations

The cassava starch industry has developed largely under a free market system, with limited governmental intervention. The EEC's CAP triggered off the rapid development of cassava exports for animal feed in the 1970s, causing the whole industry to shift from starch processing to the processing of cassava exports for animal feed.

Although, by percentage, the proportion of cassava starch exports to total cassava exports decreased from 25% in 1966 to 11% in 1991, starch exports themselves increased at an annual growth rate of 5.5%. USA and Japan have formed the major market for Thai cassava starch since 1966, despite competition with domestic maize starch. During the 1980s, Taiwan became the third most important market for Thailand, using Thai starch in modified-starch processing and other industries.

In 1982, the EEC-Thai Cooperative Agreement was signed; it set a maximum import quantity of 21 million tons over 4 years. The Agreement also obliged Thailand to actively search for other uses of cassava, finally settling on value-added cassava starch, that is, modified starch, for Japan.

Cassava starch was already produced for domestic consumption, both as food and industrial raw material, and, in relatively larger quantities, for export. In 1965, the estimated total domestic consumption was 44,557 t, and exports were 148,206 t. During 1965 to 1980, starch was used mostly in food industries (27%), the manufacture of MSG (22%), paper industry (16%), and household consumption (16%).

Thailand's outstanding economic performance during 1980-1990 in both industrial and agroindustrial sectors drew the attention of cassava starch entrepreneurs to the domestic use of starch and its potential. During 1990-1991, a survey was carried out to estimate domestic starch consumption in various Thai industries, and to project starch use in the next decade.

In the early 1990s, fewer than 50 cassava starch plants were actively operating, with a total capacity of about 1.4-1.6 million tons of starch per year. This compares with the 2 million tons that 84 plants produced in the late 1980s. Of the plants remaining, 17 were modified-starch plants, with an estimated capacity of 300,000 t/year and an actual production of 250,000 t.

Domestic cassava starch consumption was projected (as described in "Current and Future Domestic Use and Export," p. 59-65) to the year 2001 as almost 1.2 million tons. Domestic consumption and use in food processing will decrease to 18%. Use in textiles will decrease to 2%, and in plywood to 0.2%. In contrast, starch consumption in the manufacture of MSG and lysine will increase to 27%, and in the paper industry to 13% (Table 2).

Total cassava starch use in 1991, that is, the sum of total domestic consumption plus total exports, was more than 1.2 million tons. It may increase to more than 2.5 million tons by the year 2001, assuming Japan and Taiwan as the only two major export markets.

Despite the fact that domestic consumption of cassava starch has increased over time, domestic prices depend heavily on export prices, especially those of modified starch in recent years. For the future, the cassava starch industry, and the cassava industry as a whole, will still be export oriented. The EEC's CAP reforms, which reduced domestic cereal prices by 29% for July 1993 to June 1996, will therefore strongly influence the Thai cassava industry.

The impact of reduced cereal prices in the EEC (to ECU 117/t in 1993-1995) on Thai pellet prices in Rotterdam was to reduce them to ECU 93/t. This reduced price, in turn, reduced the farmgate price of cassava roots in Nakhon Ratchasima Province, Thailand, to US$23/t in 1993/94, only slightly above production costs. These reduced prices may make the cassava starch industry the major buyer of roots in the domestic market.

But if the CAP reforms drastically decrease the exports of Thai cassava products to the EEC, then cassava production would decrease in the future, creating problems of supplies for cassava starch plants. To overcome these problems, starch plants and cassava farmers may find that contract farming would be mutually beneficial.

Despite the uncertainty of the kind of impact the CAP reforms will have on the Thai cassava industry, both domestic cassava starch consumption and starch exports are likely to increase. As a whole, the Thai cassava industry is an export-dominated industry that has faced many trade restrictions. The outcome of the GATT Uruguay Round of trade negotiations will strongly influence the cassava industry, especially the starch sector.

Each cassava-producing country should take this opportunity to review the potential of its cassava starch industry in terms of its economic comparative advantage over other starches produced domestically and of its international economic comparative advantage.

As far as the future development of the Thai cassava industry as a whole, and its starch industry in particular, is concerned, the following recommendations are suggested:

(1) Research on new uses for both cassava roots and starch should be carried out as a joint effort between private and public sectors;
(2) Research on cost-reduction technologies in cassava production should be enhanced and disseminated to farmers as soon as possible;
(3) Coordination and cooperation between public and private sectors should be strengthened through frequent dialog and consultation; and
(4) Short- and long-term governmental policies on the cassava industry as a whole should be formulated.

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CHAPTER 10

SWEETPOTATO FLOUR AND STARCH: ITS USES AND FUTURE POTENTIAL[1]

*Nelly Espínola**

Introduction

In terms of production, sweetpotato (*Ipomoea batatas*) is the fifth most important crop in developing countries (Table 1). Latin America, its place of origin, paradoxically accounts for only 1.8% of world production (Table 2) (Scott, 1992).

In Peru, this root crop is used mainly for direct human consumption (96%) and its foliage or lianas are fed to animals (90%). In other countries, like the Philippines, the tender parts of the foliage are also eaten as a vegetable (Woolfe, 1992).

In China, the world's leading producer of sweetpotato, its use has varied over the last 20 years, decreasing for human consumption (from 60% to 40%), and increasing for animal feed (30% to 45%) and industrial use (5% to 10%).

About 90% of sweetpotato foliage is used for animal feed. Although it has a low carbohydrate content, its levels of fiber, protein, and vitamins are higher, thus stimulating milk production in cattle. Sweetpotato production may vary from 4.3 to 6.0 t/ha of dry matter, depending on the variety (Ruiz et al., 1980). It can also be grown as a perennial crop, tolerating foliage cutting every 3 to 4 months, depending on where it is

Table 1. Food crop production in developing countries, 1961-1988.

Crop	Production (thousands of tons)
Paddy rice	449,968
Wheat	214,119
Maize	184,927
Cassava	137,412
Sweetpotato	125,359

SOURCE: Food and Agriculture Organization of the United Nations (FAO), Basic Data Unit, unpublished data.

Table 2. Sweetpotato production in developing countries by region, 1961-1988.

Region	Production (thousands of tons)	(%)
Africa	6,263	5.0
(Sub-Saharan)	6,192	
Asia		
(China)	116,811	93.1
	108,062	
Latin America	228	1.8
Total	125,359	100.0

SOURCE: Food and Agriculture Organization of the United Nations (FAO), Basic Data Unit, unpublished data.

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1. No abstract was provided by the author.

grown (either coastal regions or highlands) (Beaufort-Murphy, 1993, personal communication).

A new variety is to be released to farmers; it is high yielding for forage, with high leaf protein content (up to 19% dry base) and very low trypsin-inhibitor content. This variety can also be grown in the highlands during the dry season when natural pastures become scarce.

In a study carried out in Peru, the costs of cultivating sweetpotato were found to be lower than those of other crops like potato and maize. It can be harvested two or three times a year and so is considered a staple crop for both human and animal consumption (Achata et al., 1990).

As a food product, sweetpotato is a source of energy, proteins, provitamin A (β-carotene), vitamin C, and iron. It ranks among the crops generating the highest carbohydrate content per hectare (156 MJ/day) over a relatively short period (120 days), even when low levels of fertilizer and pesticide are applied.

The germplasm bank at the Centro Internacional de la Papa (CIP), Peru, is a source of important genetic diversity with great potential for improving the crop for human and animal consumption and industrial purposes.

Peru has some experience in sweetpotato cultivation, but this crop is grown mainly in countries like Japan, China, Vietnam, and the Philippines, where it is used in foodstuffs, animal feed, and industry. Sweetpotato processing is increasing in importance in these countries and considerable information is available on the topic. If this information were adapted to Peruvian conditions, it could yield rapid results, making investment in sweetpotato products comparatively cheaper than that in other crops.

This paper reviews sweetpotato processing at rural and industrial levels for both human and animal consumption; and the effects its promotion would have on production, rural and urban employment, savings in foreign exchange, and stimulating agroindustrial activity.

Unprocessed Sweetpotato

In Peru, sweetpotato is boiled, fried, baked, or mashed. Its raw roots can be grated and used to make bread or sweets like *camotillo*. Sweetpotato roots can also be used in cattle feed as raw chips mixed with fibrous feedstuffs. Animals seem to find sweetpotato palatable, searching in their mixed feed to consume it first.

A dairy in the Cañete River area, the largest sweetpotato producing region of Peru, used sweetpotato in its cattle feed, thus considerably increasing the daily milk production from 25-26 L/head (1992) to 30 L/head (1993) (Espínola, 1992).

Bread made with sweetpotato purée

Bread is an important item in the Peruvian diet, but imports of wheat flour for bread making are costly. Since the 1960s, researchers have sought ways of substituting wheat flour with sweetpotato flour. The Universidad Nacional Agraria "La Molina" and a bakery in Chincha (near Lima), for example, have started manufacturing composite-flour specialty breads, both loaf and cake-type, which include boiled, peeled sweetpotato, substituting as much as 40% of the wheat flour (Peralta et al., 1992).

Bread made with raw, grated sweetpotato

Peru. The use of raw, unpeeled, grated sweetpotato to make an economic bread is being introduced; sweetpotato substitutes for 30% of the wheat flour. A "grainy" bread is obtained, with a slightly sweet taste, resulting from the very sweet commercial varieties used. Its nutritional quality is similar to that of traditional bread made with 100% wheat flour (Denen et al., 1993). CIP is collaborating with the Universidad Nacional Agraria "La Molina" to improve this sweet bread's recipe, appearance, shelf life, and crumb (or "grain") size. Initial efforts, in which the peel was discarded and the roots finely grated, succeeded in substituting as much as 50% of wheat flour (20% dry base) with sweetpotatoes.

Burundi. Bread preparation with raw, grated sweetpotato was introduced to Burundi, eastern Africa, where the technology was adapted. White varieties, with dry matter contents ranging from 25% to 30%, were used to replace 30% of the wheat flour. Modifications included fine grating of peeled roots, oil instead of lard, and the elimination of enhancers. Egg whites were added as a final touch, to give the bread a look similar to the Peruvian *pan de yema*.

Costs were lower than for 100% wheat bread but the selling price was the same. This meant a higher profit for the baker and a reduced use of wheat flour, with subsequent savings in foreign exchange (Berrios and Beavogui, 1992).

Processed Sweetpotato

Processed sweetpotato products include snack foods, such as fried chips and caramel-coated chips, and industrial products such as sweetpotato flour, purée, and starch. A large variety of starch-based products exists, and Japan has given high commercial value to raw sweetpotato starch.

Flour: Peru

If sweetpotato varieties with a high dry-matter and starch content, and a low oxidation rate are processed, a higher percentage of flour is recovered (Table 3).

CIP is collaborating with the Universidad Nacional Agraria "La Molina" to test both sun- and oven-dried flour in poultry rations. The optimal level of maize substitution and the better type of flour (raw or cooked) will be determined. In another study, with pigs, conducted by the same university, oven-dried sweetpotato was used to determine the optimal substitution level, according to animal age.

Commercial production of sweetpotato flour, supported by the private sector, is just beginning, and new products for subsequent commercialization are being developed. Commercially, sweetpotato flour can be used to substitute wheat flour in bread making or maize flour in balanced feeds (in 1992, maize imports were more than US$82 million). Sweetpotato flour will be analyzed to identify its chemical components and contaminants, and to determine its digestibility and potential uses in human and animal consumption.

Companies are producing sweetpotato flour through a novel, low-cost industrial process that processes the roots either continuously

Table 3. Percentage of flour recovered from different varieties of sweetpotato.

Country	Variety	Flour yield (%)
Philippines	Georgia Red	12.0
	Ilocos Sur	37.0
Peru	Jonathan (commercial variety)	28.6

(500 kg/h), taking 8 to 10 min; or in batches (less than 500 kg/h), taking 45 to 60 min. Flour yield for commercial sweetpotato varieties is 28.6%, that is, 3.5 kg of fresh sweetpotatoes produces 1 kg of flour (Vásquez, 1994).

First, sweetpotatoes are selected, then washed and peeled mechanically, only partially removing peel and foreign material by abrasion. Milling, that is, rasping the root at high velocity, follows. A very fine product is obtained, which is then pressed to eliminate water, resulting in a pressed cake with 38% moisture. Some solids containing starch, β-carotene, sugars, and proteins are eliminated with the water but are later recovered by decanting and incorporated into the flour during drying. The flour is dried at 40 °C for 8 seconds in a current of hot air produced by propane gas (for table flour) or by carbon briquettes (for animal feed). The flour is packed in 50-kg plastic bags through a feeder hopper.

Production costs for a volume of 700 t are US$150/t, and the selling price is US$190/t. To maintain optimal sanitary conditions, stainless steel materials are used in the equipment.

Purée

Philippines. Because this process involves advanced technology, high-quality varieties should be used to obtain a maximum yield. Developed countries, such as the USA or Japan, produce sweetpotato purée on a large scale. In the Philippines, a powdered product for preparing sweetpotato mash and "Cantonese" noodles, has developed through a collaborative project between the national agricultural program and Visayas State College of Agriculture (ViSCA). This powder is also the main ingredient for instant soups and traditional breakfasts.

Peru. The sweetpotato processing industry is just beginning and only one company is producing flakes from sweetpotato purée under the commercial trade name "Menú." This product can be used to prepare baby foods or school breakfasts, but high production costs are still a constraint (Denen et al., 1993).

Sweetpotato starch

The granule size of sweetpotato starch is similar to that of cassava, with only 5% of the total being very small and colloidal, and easily lost during water extraction. Both sweetpotato and cassava starches, when submitted to X-ray diffraction, have type-A structures commonly found in cereals. The ratio of amylopectin to amylose is 3:1 and, in some cases, 4:1 (Woolfe, 1992).

Gelatinization temperature and type are important in feed formulas, varying with variety. Gelatinization temperatures from 58 to 69 °C, 58 to 75 °C, and 65 to 80 °C have been reported. The degree of association between molecules is much greater than in potato and similar to that found in cassava.

Raw sweetpotato starch is much more resistant to the action of digestive enzymes (2.4%) than are maize (9.2%) and wheat (17.6%) starches. The degradation time of raw sweetpotato starch is 15% in 6 h compared with 20% for cassava and 10% for yam. Amylose degradation capacity increases when starch granules are ruptured, improving in pelletization (animal feed) and reaching a peak in cooking.

Asia. In countries like China, Taiwan, and the Philippines, sweetpotato is grown on small farms, where the raw roots are cut into long chips or flakes and sun-dried. The dried product is then sent to distilleries and starch factories for further processing.

In Korea, Taiwan, and Japan, about 8%, 16%, and 28%, respectively, of the sweetpotato production is used as raw starch in the food industry, for making bread, biscuits, cakes, juices, ice cream, and noodles. The starch is also converted into glucose syrup or isomerized glucose syrup (where some of the glucose has been converted into fructose to sweeten it further).

In Japan and Korea, starches and other fermentable carbohydrates are used to distil a typical liquor called *socchu*. Lactic acid, acetone, butanol, vinegar, and leavenings are also produced by fermentative processes.

Japan has developed a cyclodextrin with diverse, high-value uses in the food and pharmaceutical industries and in blood tests.

China. Sichuan Province is the world's largest producer of sweetpotato, most of which is used in processed products and animal feeds. The crop forms the major source of income for most of the inhabitants. Simple, small-scale technology is used to produce starch and noodles. The noodles are similar to the rice noodles (or Chinese noodles) commonly used in the dish *chifa*.

Three different methods of starch extraction are employed, with differing percentages of recovery: the water precipitation method (12%-14%); the natural precipitation method (16%-18%); and the liquid acid method (17%-20%) (Timmins et al., 1992).

Residues are peelings and fiber, which are fed to pigs either directly or after fermentation, or after being dried and mixed with other types of forages such as maize stalks or rice hulls (CIP, 1991).

Peru. The prospects for starch extraction in Peru are good, especially in rural agroindustry, as are potato and maize starches, both widely used in the country. Sweetpotato starch could be used in the food, textile, glue, paint, and cardboard industries. A company has begun manufacturing starch extraction equipment adapted to small- and medium-scale farming conditions.

CIP's Plant Breeding Program has developed advanced clones, with adequate processing characteristics, that are undergoing final testing and selection for release by the Instituto Nacional de Investigación Agraria (INIA). The clones should have high dry-matter content, high yields, low oxidation rate, low fiber content, and very low latex content (Table 4).

Table 4. Preliminary data of clones selected for starch content[a] and suitable for industrial processing, Peru.

Clone	Color	Dry matter (%)	Starch (%)
SR 87.070	White	37.6	25.83
SR 90.012	Cream	38.6	23.66
SR 90.021	Cream	30.0	20.30
SR 90.323	Orange	42.8	22.80
YM 89.240	White	35.2	23.41
YM 89.052	White	29.8	20.47

a. Analyses carried out by Derivados del Maíz, S. A. (DEMSA).

INIA is also assessing about 1,000 clones for human consumption, processing, and forage purposes in the Cañete region. A private company has evaluated 42 of these clones for dry-matter and starch contents. Six clones had high yields, and high dry-matter and starch contents, indicating broad potential for further research (Table 4).

Agroindustrial Prospects

The following list summarizes the agroindustrial prospects of sweetpotato:

(1) Grated, raw sweetpotato for preparing an economic bread.
(2) Sun-dried flakes for producing starch, alcohol, or flour for human consumption, animal feed, and industry.
(3) Sweetpotato flour for preparing porridge, breads, biscuits, and balanced feeds for poultry and swine (replacing maize).
(4) Sweetpotato starch for preparing noodles and glucose syrup (dextrins). Peru imports glucose to produce pharmaceutical syrups, caramels, and gum drops. It is also used by the textile and glue industries.
(5) Production of alcohol (Japan, Korea).
(6) Sweets (e.g., flakes and caramels).
(7) Ketchup (Philippines).
(8) Fruit-flavored juices (Philippines).
(9) Liquor (Japan, Korea).
(10) Balanced feeds for poultry and swine (replacing maize).
(11) Extracting anthocyanin, a natural purple coloring used in preparing ice cream, yogurt, and pastries.
(12) Sweetpotato pastes with high β-carotene content for baby foods.

Conclusions

The potential of sweetpotato processing will be realized if:

(1) Sweetpotato breeding is directed toward processing. This means using the world collection of germplasm and installing facilities for conducting production trials at different sites.
(2) Collaborative research projects are conducted to develop new products.
(3) Information on experiences in other countries is collected and organized to help design strategies and policies that would support sweetpotato processing.
(4) The private sector participates actively. Links must therefore be established with the private sector.

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CHAPTER 11

PROSPECTS FOR CASSAVA STARCH IN VIETNAM[1]

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Introduction

As the third most important crop after rice and maize, cassava accounts for 30% to 40% of secondary food production in Vietnam (Thang, 1993). The total production of cassava was 2.47 million tons of fresh roots in 1992 (Statistical Yearbook of Vietnam, 1993) planted on 277,200 ha. The Vietnamese Government has shown interest in this root crop as a cheap raw material for further processing.

In 1989, the Vietnamese Root and Tuber Research Program was founded as the first step toward strategically reorganizing root crop research in Vietnam. In the past, most efforts in agricultural research and development in Vietnam concentrated on production and little is known about consumer and user needs. From 1990 onward, with CIAT's assistance, a series of cassava production, processing, and marketing analyses were conducted in Vietnam, aimed at identifying and analyzing constraints and opportunities for the cassava sector. The 1991 cassava benchmark study (Howeler, 1996) included household surveys, focusing on cassava production, on-farm processing, use and consumption, and rural, semiurban, and urban marketing. Also included were processing surveys, which focused on the technical and socioeconomic aspects of different products processed and major marketing channels.

Results from an analysis conducted by Henry et al. (1993) on the main constraints to cassava production, productivity, processing, and marketing could serve as a base for strategic research planning in Vietnam. Cassava-based products seem potentially significant for the future. Henry et al. (1993) also reviewed the products and market opportunities of cassava in Vietnam, but data were scarce and information incomplete.

For decisions on future cassava research and development in Vietnam, additional in-depth studies are required to analyze current and future potential demand of different cassava-based products. Research on market demand is important because consumer needs (including industry, on-farm use, etc.) should first be assessed and then production,

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1. No abstract was provided by the authors.

processing, and marketing technology geared to address specific opportunities.

This study aims, first, to analyze current use of, and relative quantities of, starch for different end products; second, to estimate starch demand of these products for the future; and third, to recommend issues for future cassava research and development activities.

Methodology

Data were collected by interviewing processors, traders, personnel from export companies, and manufacturers who use cassava starch as a raw material. With manufacturers, the interview format included questions on production level, current inclusion ratio of cassava starch, production technology, technical requirements for cassava starch, its growth rate, and future demand. The time series data available on cassava starch consumption for each end product and for the manufacture of some products are neither reliable nor consistent. Future cassava starch demand was therefore estimated by using a simple method based on population and income growth.

Current Cassava Use

Cassava roots have been used for different purposes such as animal feed (flour), starch production (wet and dry starch), fresh roots for human consumption, dried chips for export, and home-processing purposes such as maltose and alcohol (Table 1).

Fresh roots (for human consumption) and flour for animal feed (both at the farm and by industry) account for about 73% of the total cassava production in Vietnam. Total production of pigs was about 13.9 million head and of poultry, about 124.5 million head, representing the use of about 1.4 million tons of cassava roots. Cassava starch production is the second source of root consumption, representing about 16% of total production. Chips for export account for almost 5%, and home-processing (not including dried chips) 6%.

Currently, dried cassava starch is used in food processing and for home consumption, exported, and used by several industries such as textiles, pharmaceuticals, cardboard, monosodium glutamate (MSG), glucose, maltose, and plywood. The

Table 1. Cassava consumption in Vietnam, 1992.

Use	Quantity of fresh roots	
	(t)	(%)
Fresh roots (human consumption)	301,376.60	12
Animal feed (by farmers and industry)	1,503,845.90	61
Dried chips for export	120,000.00	5
Starch production:		
Dried starch (80%)	316,062.00	
Wet starch (20%)	79,015.50	
Total starch (100%)	395,077.50	16
Home processing (dried chips and starch not included)	150,000.00	6
Total	2,470,300.00	100

total demand for cassava roots for starch production (both wet and dried) was about 395,077 t in 1992. About 20% went to wet starch production, mostly for local processing into low quality noodles (Binh et al., 1992).

Cassava Starch Processing and Marketing

During the Vietnamese cassava benchmark survey in 1991, cassava starch processing was found to be practiced in most of the provinces surveyed. But the largest cassava starch processing areas are in the provinces of Dongnai and Tayninh, and Ho Chi Minh City. Cassava starch is produced either dried (about 80% of the total starch production) or wet (20%) (Binh et al., 1992).

Most cassava starch production is conducted by the household or village. It is constrained by traditional technology (low conversion rates), limited and fluctuating root supplies, seasonality, restricted capital, and poor market organization. These lead to low profits and fluctuating quality and levels of supply. Some large processing plants also use old technologies. Currently, investors are interested in improving cassava starch processing technologies.

Current Use of Cassava Starch in Vietnamese Industry

Table 2 summarizes current cassava starch use. Most dried starch is consumed at home (about 57%) and by food processing industries (about 36%).

Food processing and home consumption

Households form the largest group of consumers of cassava roots (about 60,000 t/year). Cassava starch is

Table 2. Use and quantity of starch in different end products, 1992, and potential demand of cassava by year 2000.

End product	Starch consumption		Potential demand in year 2000	
	(t)	(%)	(t)	(%)
Dried starch				
Food processing	25,000	35.60	30,000	16.51
Home consumption	40,000	56.95	45,000	24.76
Textiles	1,550	2.21	2,000	1.10
Monosodium glutamate	0	0	90,000	49.53
Carton	600	0.85	1,200	0.66
Glue (other purposes)	50	0.07	150	0.08
Plywood	96	0.14	120	0.07
Maltose	40	0.06	100	0.06
Glucose	1,800	2.56	3,000	1.65
Pharmaceutical products	100	0.14	150	0.08
Exports	1,000	1.42	10,000	5.50
Total	70,236	100.00	181,720	100.00
Wet starch				
(Cakes, noodles, etc.)	17,559		18,000	
Total starch consumption	87,795		199,720	
Fresh root consumption	395,077		898,740	

used to bake cakes, fry meat and fish, make soup, and cook other traditional Vietnamese dishes. Cassava starch is bought from retailers, who obtain it from wholesalers in urban and local markets, who, in their turn, receive it from processing centers.

The food processing industry, currently the country's second largest consumer, uses about 25,000 t of high quality dried cassava starch per year. A diverse range of products is made, including bread, rice chips, and cakes. About 30% of total starch used in rice chips is cassava. For making cakes, cassava starch is mixed with other starches from soybean, green bean, rice, and wheat flours. To be competitive with other starches, cassava starch must be cheap and of high quality.

Monosodium glutamate production

The total MSG used in Vietnam is currently about 40,000 t/year. Most is imported from Japan, Taiwan, and Singapore, with only a small amount produced nationally. In the 1980s, Vietnamese companies produced MSG, using as raw material either cassava starch (75%) or byproducts from the sugar industry (25%). These companies used old technology with low conversion rates: 6-6.5 t of cassava starch produced 1 t of MSG.

Cassava starch was obtained from processing centers through wholesalers. A starch quality of 90%-92% purity was required. Constraints included fluctuating starch quality as a result of processors using different technologies; and erratic supplies because root availability depended on harvest seasons. The MSG companies had to store starch, but often lacked good storage facilities, which, with the starch's variable consistency and low quality, caused quality losses.

The low conversion rates, poor product quality, and high production costs made local MSG unable to compete with imported MSG. Thus, many companies ceased production or attempted to modernize their technology, sometimes through joint ventures with foreign partners. The production of MSG decreased from 2,003 t in 1987 to 721 t in 1992 (Statistical Yearbook of Vietnam, 1993). In 1987, almost 12,000 t of cassava starch were used by this industry. But with modern technology, MSG is produced mostly from imported glutamate azide and not from cassava starch.

Since 1990, several foreign multinationals have entered the MSG sector. At first, they imported MSG to sell in Vietnam, but after conducting market research, they concluded that producing MSG in Vietnam was a viable option. Currently, they are producing MSG from glutamate azide imported from the mother company. At the same time, they are researching the market potential of MSG produced from local raw material, availability of raw materials (cassava starch, byproducts from the sugar industry, and other starch sources), possible sites, and production organization. Four new MSG factories, with a capacity of 35-40 thousand tons/year, are now being planned.

Textile industry

About 1,550 t of cassava starch are currently used per year by the textile industry as size for weaving cotton fabrics. Other possible substitute starches are maize, wheat flour, potato, and rice. In the past, some textile factories in northern Vietnam used maize starch, which was more readily available in the Red River Delta than cassava starch. Later, as supplies increased, most factories changed to cassava starch, which is technically more suitable and also cheaper. The Government also encouraged the industry to replace starches from other food crops with that from cassava.

Starch supplies arrive at the factories from the processing centers through wholesalers. The average price of high quality cassava starch, in Vietnamese dôngs (VND), is about VND 2,000 to VND 2,200/kg. Starch for the textile industry must be homogeneous in quality, pure (92%-95%), highly adhesive, white—with no change in color—unfermented, and resistant to quality loss when stored.

Some textile factories use modern weaving machinery that has a high production capacity and high weaving speed. Such machinery requires high quality glue, which is imported. This glue could be made from chemically modified cassava starch, a product that is likely to be used by the textile industry in the future. But raw cassava starch will still be used in small weaving factories, and for producing the currently imported glue.

Glues for cardboard production and other purposes

To produce cardboard and other packing materials, starch from wheat flour, maize, rice, and cassava is used as glue. In Vietnam, cassava starch and flour are readily available and relatively cheap. Small cardboard-producing units with simple technology use both cassava flour and starch, but large modern factories use only cassava starch, as the flour does not reach technical standards. Cassava starch must be highly adhesive and pure (90%-92%). Whiteness is not so important. Most processing centers can satisfy these criteria.

About 200 kg of cassava starch are needed to produce 5 t of cardboard. Currently, about 600 t of cassava starch are used to produce an annual 15,000 t of carton.

The estimated consumption of cassava starch for glues for other purposes, such as for offices and packing materials, is about 50 t/year.

Maltose and glucose production

Maltose production in Vietnam consumes about 40 t of cassava starch annually, and that of glucose about 1,800 t. To produce 1 t of maltose, about 1-1.5 t of cassava starch is needed, and for 1 t of glucose syrup, about 300 kg.[2] Starch has to be at least 90% pure for these two products. Maltose and glucose are used by the pharmaceutical and food-processing industries, which thus govern demand.

Plywood industry

Together with urea, formaldehyde, and other chemicals, cassava starch is used to produce industrial glue for plywood production. To produce 1 m^2 of plywood, 0.46 kg of industrial glue is used, of which about 30%-35% is cassava starch. Wheat flour could also be used, but, because of its relatively low price, cassava starch is preferred. Starch must be pure (less than 5% of substance remaining after burning), with a pH value of 5.5 to 6 (in unfermented starch), and contain less than 10% cellulose. Whiteness is not important. Current plywood production is about 700,000 m^2, consuming about 96 t of cassava starch annually.

2. Glucose syrup is a concentrated aqueous solution of saccharides derived from the original starch. Hence, a greater weight of syrup is obtained from a given weight of starch.

The proportion of cassava starch in glues for plywood is relatively high in Vietnam. In the 1980s, the cost of glues was about 30%-35% of total production costs. Producers therefore reduced production costs by including high rates of cassava starch (35%), which decreased the product's quality. As chemicals for glue manufacture became cheaper, the proportion of cassava starch dropped from 35% to 30%.

Pharmaceutical industry

At present, the pharmaceutical industry uses cassava starch to produce medicinal tablets and pills. Purity, whiteness, and adhesiveness are the most important criteria, which traditional technology usually does not meet. Thus, starch bought from processing centers has to undergo further processing to reach the needed quality. About 100 t of cassava starch is consumed annually by this industry.

Despite the extra processing needed, cassava starch is cheaper than other starches such as rice or potato, and is in plentiful supply. The technology for using cassava starch is also more readily available.

One constraint is that, under some circumstances, the adhesiveness of dried cassava starch is not as good as that of other starches. For example, in the processing of certain medicines, water cannot be used because it may interfere with the medicine's effects. Research is therefore needed on technologies that can directly use dried cassava starch in producing tablets and pills.

Although cassava processing factories specializing in starch for pharmaceutical use satisfy the industry's requirements, the quality of cassava starch urgently needs improving to produce high quality dextrin, maltose dextrin, and glucose for pharmaceutical use.

Exports

Vietnam exports mostly dried cassava chips and only a small quantity of dried cassava starch. About 30,000 t of cassava chips is exported annually to the European Union (EU), 10,000 t to Asian countries, and only 1,000 t of cassava starch and tapioca pearl to neighboring countries. Cassava chips exported to the EU cost US$120 to US$130/t, whereas chips to Asian countries cost US$70 to US$80/t. Because of the higher prices of exports to the EU, the local price of dried chips has increased and exports to Asian countries have dropped. Asian export companies have therefore changed to exporting cassava starch or tapioca pearl.

Major constraints to cassava starch export, however, are poor starch quality, inefficient processing and marketing system, shortages or poor storage facilities, relatively high transport costs, and insufficient supplies. The current conversion rate from fresh root to dried starch in processing is 5:1 in the wet season and 4:1 in the dry season. Dry matter content is high in the dry season but farmers set their cropping calendar so that they can harvest in the wet season when less labor is needed, but when both starch content and conversion rates are low and the high humidity makes drying the starch difficult. Many processors therefore cannot produce export quality starch. The small-scale processing and low starch quality make collecting enough starch for export difficult. These constraints make Vietnamese cassava starch noncompetitive with starch from China and Thailand.

Although labor is cheap and farmgate prices are low in Vietnam, Thailand has more advantages for producing cassava starch. These are lower prices for fresh roots (farmgate price is about US$20/t), large-scale and highly efficient processing, a very efficient marketing system with good storage facilities, high starch quality, large volumes, and low transport costs.

Nevertheless, foreign companies with high production capacity, better technology, and better export facilities have invested in cassava starch production in Vietnam. These investments may generate an increased opportunity for cassava starch exports in the future.

Cassava Starch Market Potential

Future domestic demand for different end products

Cassava starch consumption is currently important, accounting for about 20% of the total cassava production. Assessments of the stability of this status revealed considerable future potential, with increasing demand from the MSG and other food processing industries, and household consumption.

The demand for MSG is expected to grow to 60,000 t by the year 2000. Although MSG production for domestic consumption is growing, increasing production for export is difficult because neighboring countries also produce MSG, and in sufficient quantities for their own consumption. MSG production in Vietnam therefore satisfies mostly domestic demand.

Currently, most companies are using imported glutamate azide to produce the MSG, but the potential for cassava starch is high, even with byproducts from the sugar industry as an alternative source of starch. Modern technology and suitable bacteria will help increase the conversion rate from cassava starch to MSG. Despite the increased use of byproducts from the sugar industry (because of their lower prices), the demand for cassava starch will still be high, probably at about 90,000 t/year in the year 2000.

However, some constraints operate against using cassava starch in this industry, one of which is the large volumes of starch needed daily as raw material. For example, to produce 10,000 t of MSG per year, a company needs about 29 t of cassava starch of 90% purity per day. About 116 t of fresh roots per day are needed to produce this amount of starch. Hence, obtaining sufficient supplies under current conditions is difficult. Even collecting such large volumes is costly, especially in areas where cassava production is not concentrated. Transport costs are acceptable up to a distance of 120 km around the plant, but organizing the collection can be a problem.

Another problem is the seasonal nature of harvesting cassava, occupying about 5 to 6 months/year, coupled with a lack of adequate storage facilities. Hence, supplies of starch for year-round production are insufficient.

If these constraints could be resolved, then the demand for cassava starch for MSG production would be high.

Cassava starch, as a food for household consumption, is inferior and its demand declines with increase in consumer income. However, demand grows with population increase. With an expected population growth of 2.1% and an expected gross national product (GNP) growth of 8%/year, the demand for cassava starch for household consumption, is conservatively estimated to increase from 60,000 to 65,000 t/year by the year 2000.

In the food processing industry, as products diversify, the use of cassava starch will increase greatly in the future. Cassava starch will be used in producing higher quality food products and new ones such as different kinds of cakes and snacks. But higher starch quality will be needed.

Textile industries are expected to expand substantially. Thus, demand for high quality glues (made from chemically modified starch) and modern technology, such as high-speed weaving machinery, will increase demand for modified cassava starch, which, in turn, may encourage the local production of cassava starch. The potential demand for cassava starch in the textile industry is expected to be about 2,000 t/year.

Demand for cassava starch as raw material for glues for cardboard production is expected to increase to about 1,200 t and for other purposes to 150 t. These demands, however, account for only a small proportion of the total future starch demand.

In the plywood industry, higher quality plywood will be needed. The proportion of cassava starch as raw material for glue production will decline from 30% to 20%-25% in the future. But if plywood production increases, about 120 t of cassava will be used annually.

The demand for cassava starch for maltose production and for the pharmaceutical industry will not increase much. The demand in glucose production may be higher with about 3,000 t/year. Table 2 summarizes the estimated future demand by industry.

Export potential

By the year 2000, cassava starch exports will have significantly increased. At present, foreign companies are investing in the cassava processing sector and exporting their products. The prospects for increased exports of cassava starch are good, once large processing plants are at full capacity and using modern technology. Better facilities and high-yielding varieties with high starch content would improve the conversion ratio and starch quality, and lower production costs. By the year 2000, export volume may reach 10,000 t/year. But once the comparative advantage of cheap labor declines, more starch will be used for domestic industrial consumption.

Competition from other starches

Cassava starch has a relatively lower price than rice starch and wheat flour (Table 3), a price relationship which is

Table 3. Prices of some products in Ho Chi Minh City, Vietnam, November 1993. (VND 1,080.00 = US$1.00.)

Product	Wholesale price (VND/kg)	Retail price (VND/kg)
Cassava starch quality:		
I	2,200	2,300
II	2,000	2,200
III	1,800	2,000
Rice starch	2,900	3,000
Wheat flour	3,000	3,200
Cassava flour	950	1,300
Cassava noodles	3,200	3,300
Monosodium glutamate	5,500	16,000

unlikely to change in the future. The price of rice starch will not decline compared with that of cassava starch because of technology and because the Government will not encourage the use of rice starch in industry. Wheat flour is less competitive with industrial cassava starch because it is imported, thus using scarce currency and increasing production costs. Other starches such as cinnamon and maize are mostly used in the food processing sector, being either too expensive or too scarce for industrial use.

The influence of government policies on market potential

The Vietnamese Government emphasizes substitution by cassava and other roots and tubers to favor rice for domestic human consumption and export. The Government also encourages the export of agricultural products, including cassava-based products, such as dried chips and starch, through a zero export tax. Taxes are also used to protect domestic production by limiting the import of goods that can be produced in Vietnam. For example, the import tax on MSG and wheat flour is 20% of the c.i.f. (cost, insurance, and freight) price.

The Government policy also encourages investment in the cassava sector. These policies can greatly affect the business potential of cassava starch, especially in the MSG industry and cassava processing for export. As a result, several foreign companies have invested in these two sectors.

Conclusions

The analysis of current cassava starch use and proportion of starch in different end products reveals that food processing, household consumption, textiles, and glucose are the current major cassava starch consumers. Demand in the MSG industry is expected to increase greatly. Little change will occur in the demand for cassava starch in food processing and household consumption, which is expected to remain very high in these two sectors. In the food processing industry, products using cassava starch are highly diverse, requiring better starch quality. Cassava starch exports will also increase substantially. Demand for cassava starch by the year 2000 is expected to be more than twice the present level (Table 4).

The trend of cultivated areas in Vietnam (Table 5) shows that the area planted to cassava is decreasing and productivity is only slightly increasing. In the future, the cassava area is likely to decrease further as other industrial crops of higher value replace cassava. With the expected increase in future demand for cassava starch, a gap between supply and demand will develop. The gap will widen further with increasing demand for cassava flour for livestock and poultry feed. If cassava productivity is not improved, shortages can be expected in the future.

Because cassava area cannot be increased, extra supplies can be obtained only by intensifying cassava production. Introducing high-yielding and high starch content varieties would help solve this problem.

But introducing high-yielding varieties requires research on adopting new varieties in different agronomic regions, transferring technology to farmers, and the farmers' adopting new technology. Despite the higher yields, improved varieties require much more chemical fertilizers, pesticides, and labor than

Table 4. Potential growth of cassava starch by industry, Vietnam, 1992-2000.

Product	1992 demand (t)	Estimated demand in year 2000 (t)	Growth rate (%)
Dried starch			
Food processing	25,000	30,000	20
Home consumption	40,000	45,000	13
Textiles	1,550	2,000	29
Monosodium glutamate	0	90,000	very large
Carton	600	1,200	100
Glue for other purposes	50	150	200
Plywood	96	120	25
Maltose	40	100	150
Glucose	1,800	3,000	67
Pharmaceutical products	100	150	50
Exports	1,000	10,000	900
Total	70,236	181,720	159
Wet starch	17,559	18,000	3
Total starch consumption	87,795	199,720	127
Total fresh root consumption	395,077	898,740	127

Table 5. Total cultivated area and production of cassava in Vietnam, 1976-1992.

Year	Cultivated area (000 ha)	Production (000 t)
1976	243.5	1,843.1
1980	442.9	3,323.0
1985	335.0	2,939.8
1986	314.7	2,882.3
1987	298.9	2,738.3
1988	317.7	2,838.3
1989	284.6	2,585.4
1990	256.8	2,275.8
1991	273.2	2,454.9
1992	277.2	2,470.3

SOURCE: Statistical Year Book of Vietnam, 1993.

do local varieties, and not all farmers can afford them. Ignorance of new technology and lack of credit are further constraints to farmers' adopting new technology, requiring increased extension.

For the cassava sector and agriculture in general to develop in harmony, cassava production, processing, and marketing must be coordinated, and a favorable disposition toward cassava-based products created. Such integrated research needs cooperation among agronomists, plant breeders, processing technologists, and economists. Only by these means can possible losses to society be eliminated. For example, in 1987, farmers were encouraged to produce more cassava even though market demand was decreasing. The result was an over supply of cassava and a significant drop in the price of fresh roots. The drop was so great that farmers did not harvest.

To develop the cassava sector, the Government should provide adequate statistics and make information on prices, demand, and other marketing features widely available to help farmers, processors, and other producers decide appropriately. The Government should also clearly indicate its pricing policies.

The technical requirements of starch quantity and the quality of different end products made with cassava starch could be used as criteria for cassava production and starch processing. To satisfy future requirements for cassava starch quantity and quality, many improvements in production, processing, and marketing should be made. Traditional processing units must invest in modern processing plant and improve their efficiency, that is, have higher conversion ratios and better starch quality.

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CHAPTER 12

CASSAVA FLOUR PROCESSING AND MARKETING IN INDONESIA

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Abstract

In Indonesia, cassava is the fourth most important food crop after rice, maize, and soybeans. An average of 16 million tons of cassava is produced annually, most of which goes to starch extraction or is exported as pellets and chips. But markets are unstable and farmers have few incentives to produce more cassava.

Processing for cassava flour began in 1990 to diversify cassava products. The cassava flour agroindustry consists of three major production systems: at the farm (model 1), farmers' groups (model 2), and the mill, which acts as a nucleus by linking farmers and farmers' groups, through their fresh roots and dried chips, with cassava flour distributors and consumers (model 3). Processing capacities of the three systems during harvesting are about 75 kg of roots per day for model 1, 500 kg for model 2, and 10,000 kg for model 3. Yield recovery of 25% to 30% has been obtained for dried chips, and 24% to 29% for cassava flour.

Small farmers and farmer groups receive increased added value by producing cassava chiplets (*sawut*) instead of *gaplek* (dried cassava chips). Marketing, however, is still a major constraint for the cassava flour agroindustry.

A consumer-acceptance study, conducted in the Purwakarta region and Ponorogo district, showed that about 80% of cassava flour was considered acceptable. About 84% of consumers thought the flour was acceptable for household consumption, which was estimated at 4-7 kg/month per household. Because cassava flour can substitute wheat flour in wheat-based products by as much as 30%, the entire local production of cassava flour can be absorbed, especially by the food industries. PT Mariza, a private company, has begun industrial production of cassava flour and is developing a marketing system.

Introduction

Agriculture is an important component of the Indonesian economy, providing 49% of total employment, and about 18% of the gross domestic product (GDP). Food crops alone represent 62% of the GDP from the agricultural sector, that is, 12% of the total GDP (1991 figures).

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Rice is the chief food crop, followed by soybeans, maize, and cassava. Other secondary crops are peanuts, mung beans, and sweetpotatoes. Minor crops with a potential future in food production are several cereals, legumes, roots, and tubers.

Cassava is grown on about 1.4 million hectares throughout the country, with an average production of 16.3 million tons/year (CBS, 1992). The crop is used as food and for starch extraction, and is exported as feed (Damardjati et al., 1992). The cassava market overall, however, is unstable and tends to discourage farmers from producing cassava.

Recently, the Government began promoting cassava for industrial purposes and food. A preliminary economic analysis indicated that cassava flour production and use in processed foods would be feasible. A series of investigations on cassava flour production and use was therefore begun by several research institutes operating under the auspices of the Central Research Institute for Food Crops (CRIFC).

The CRIFC then collaborated with private companies to develop a cassava-flour agroindustry model at the village level in several locations in Indonesia (Damardjati et al., 1992).

This paper presents the results of our study on the development of the cassava-flour production system, consumer acceptance, and the marketing of cassava flour.

Cassava Production, Consumption, and Use

Production

In Indonesia during the past decade, the harvest area has decreased while both productivity and the number of cassava-growing regions have increased. (Less than 10 years ago about 65% of total production came from Java alone [Dimyati and Manwan, 1992]). Factors causing the reduced harvest area are complex: incentives and sharp price fluctuations have induced farmers to grow cassava, but factors such as establishing irrigation facilities and reforestation have reduced planting area.

The average yield per hectare of cassava is rather low at 12 t, but the trend has been toward a constant increase in yields. A much higher yield can be obtained through improved cultural practices. On the estate of a tapioca plant in Lampung, a yield of 25-30 t/ha of cassava has been continuously attained (Rusastra, 1988) as a result of a cassava intensification program started by the Government in 1975 (Dimyati and Manwan, 1992). Moreover, research findings suggest that yields can be as much as 75 t/ha.

Between 1978 and 1992, cassava production fluctuated, with a peak at 17.1 million tons during the late 1980s. In 1992, about 16 million tons were produced (Figure 1).

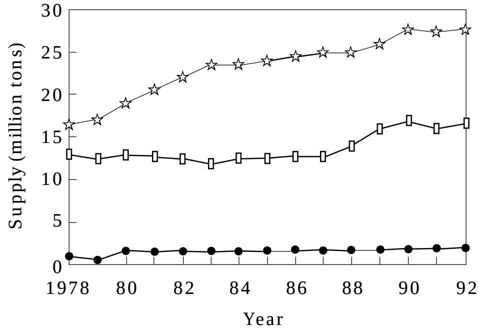

Figure 1. Domestic supply of rice (☆), cassava (▯), and wheat (●) in Indonesia, 1978-1992. (Taken from CBS, 1978-1992.)

Domestic demand and consumption

Annual per capita consumption of cassava as food has been decreasing gradually from about 57 kg in 1983 to 51 kg in 1988 (Damardjati et al., 1990). From 1988 to 1992, consumption of cassava and other secondary crops fluctuated, showing a correlation with rice consumption (Table 1).

Cassava also became an important export crop. Since 1982, Indonesia has exported a yearly quota of *gaplek* and pellets to the European Union (EU), as well as to other countries. Since 1989, Indonesia has also regularly exported tapioca starch (Table 2).

Cassava availability for domestic food consumption is related to the total export of all cassava products (chips, pellets, and starch). For example, domestic consumption of cassava in 1990 was lower than that in 1992, because exports were higher in 1990.

The consumption of cassava as a foodstuff is concentrated in Java, thus making demand more stable and easier to estimate. Outside Java, in areas such as Lampung, the international market and industrial activities influence demand.

Processing and use

According to the Indonesian food balance sheet for 1991 (CBS, 1992), total cassava production in 1991 was almost 16 million tons. Of this, almost 57% was consumed as both fresh and processed food, 21% was processed into *gaplek* and pellets, of which 41% were exported and 59% went to industry. Tapioca starch was produced from about 8% of harvested cassava, mostly for export, but, if sold on the domestic market, also for making *krupuk*. The rest is used in other food, textile, paper, glucose, and pharmaceutical industries. Postharvest losses are still relatively high at 13% (Table 3).

Cassava use in Indonesia differs throughout the country. In Java, where 60% of the population resides, cassava is primarily for human consumption. Unnevhr (1990) reported that the rural dwellers, producers, and major consumers of cassava use about 62% of roots and 49% of the *gaplek* they produce for their family needs.

Currently, the demand for cassava in Indonesia seems to have reached a plateau, but experts anticipate an increase in domestic demand during the next decade for both food and industrial purposes.

Table 1. Average per capita consumption of major food crops in Indonesia, 1986-1992.

Crop	Consumption							
	1986		1988		1990		1992	
	kg/year	cal/day	kg/year	cal/day	kg/year	cal/day	kg/year	cal/day
Rice	147.36	1,453	150.18	1,481	150.05	1,480	147.91	1,459
Cassava	51.44	154	51.00	154	43.07	129	57.40	172
Sweetpotato	11.05	32	10.93	32	9.74	28	10.34	30
Wheat	5.96	60	6.59	60	7.54	75	10.36	104
Maize	29.25	256	30.75	256	29.68	260	34.63	303
Soybean	8.80	80	9.45	80	10.72	97	12.57	114

SOURCES: CBS, 1988; 1990; 1992; 1994.

Table 2. International trade in Indonesian cassava (t), 1983-1992.

Year	Exports		Imports	
	Chips	Starch	Chips	Starch
1983	358,346	1,602	-	63,883
1984	365,161	183	-	3
1985	343,303	107,000	-	21
1986	424,600	-	165,000	20,500
1987	783,776	116,000	41,750	9,500
1988	825,000	-	250,000	23,000
1989	834,000	282,000	-	-
1990	697,000	487,000	-	-
1991	494,000	317,000	-	12,000
1992	372,000	135,000	79,000	34,000

SOURCE: CBS, 1992.

Table 3. Trends of cassava production and use in Indonesia (thousands of tons).

Item	Fresh cassava[a]					
	1986	1988	1989	1990	1991	Percentage[b] of total production
Total production	13,312	15,471	17,117	15,830	15,954	100
Losses	1,572	2,011	2,225	2,058	2,074	13
Feed for domestic use	242	309	342	317	319	2
Roots for chips			4,281	3,900	3,336	21
Total chips produced			(1,540)	(1,403)	(1,200)	
Exports	(424)	(825)	(834)	(697)	(494)	
Tapioca starch			1,150	1,881	1,232	8
Domestic use			(322)	(527)	(345)	
Exports			(282)	(487)	(357)	
Food consumption	8,573	8,863	9,119	7,674	8,993	56
Food industry			5,431	5,781	4,568	

a. Values in parentheses indicate dried cassava.

b. Percentages are rounded.

SOURCES: CBS, 1988; 1990; 1991; 1992; 1993.

Developing of Appropriate Technology for Cassava Flour

Developing diversified uses for cassava and the appropriate technology should extend the market and strengthen farmers' bargaining power in that they would have other buyers available and could command better prices. New alternatives for cassava use should be simple and easy, and give added value directly to the farmers.

The Indonesian Government is attempting to develop the potential of cassava flour as a food for domestic consumption and as a raw material for both household consumption and the food industry to complement or substitute wheat flour. The Government has recommended that the agricultural and industrial sectors make special efforts in promoting cassava by diversifying cassava processed products, improving their quality, and promoting their use among the different strata of the Indonesian population.

Several research institutes, the public sector, and private companies have developed machine prototypes for cassava processing and new recipes for preparing food using cassava products, and have promoted the use of composite cassava-wheat flour in preparing foodstuffs such as breads, pasta, and cookies.

The use of a model of an agroindustrial system based on cassava flour production would support efforts to transfer technology from researchers to farmers, who could then commercialize the system. The system would then be supported by a continuous distribution and marketing system.

Developing the processing operation

To produce cassava flour, roots are peeled, washed, chipped, pressed, dried, ground or milled, and then sieved (Damardjati et al., 1992). The village distribution and processing system commonly used for handling agricultural products involves three types of processor groups: (1) individual farmers, (2) farmers' groups, and (3) groups of village union cooperatives, known as Koperasi Unit Desa (KUDs), processors, millers, and cassava flour producers. Figure 2 shows the overall cassava processing system, with three tradable products produced during the processing of flour from harvesting to marketing: (1) roots, (2) dried cassava chips, and (3) cassava flour.

Models for cassava flour production

The KUD or other entrepreneur group is appointed as the nucleus processor responsible for cassava-flour processing and marketing. Three models of cassava flour production can be derived from the overall pattern of cassava distribution and marketing and transaction products. The models are individual farmers (model 1), farmers' groups (model 2), and cassava

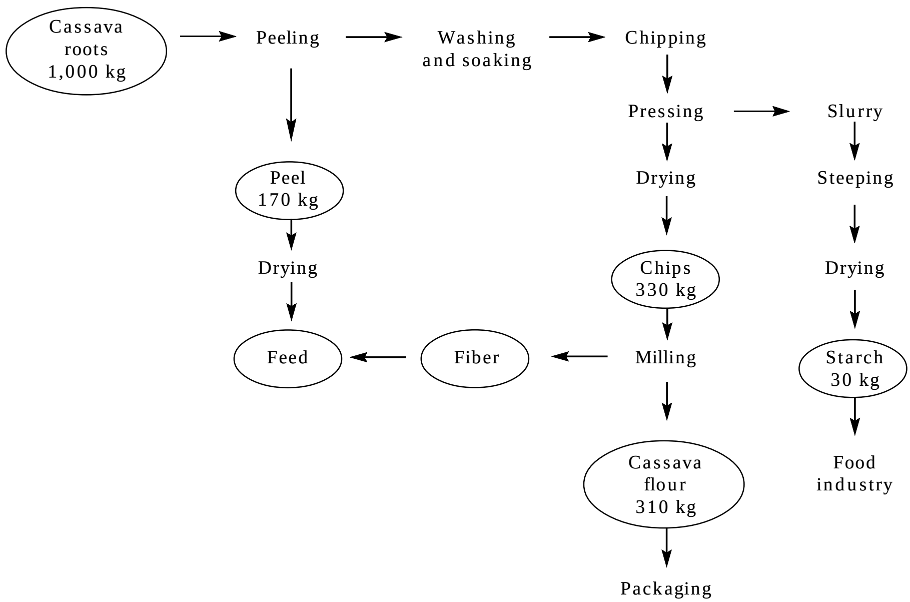

Figure 2. Model of cassava processing system in Indonesia. Ovals indicate tradable products.

flour plants that act as nuclei that link farmers and farmers' groups, by buying their fresh roots and chips and milling them, with distributors and consumers (model 3) (Damardjati et al., 1992).

Developing the Agroindustry for Cassava Flour Processing

With finance from its own project budget, the ARM-AARD project, and the Government Corporation (PT Petro Kimia Gresik), SURIF undertook to develop and establish a project to develop a cassava-flour agroindustry for village farmers. PT Petro Kimia Gresik acted as the nucleus company.

Site selection

Several sites were chosen for the project, based on the following criteria:

(1) Desire to participate, and participation, on the part of farmers (or farmers' group) and the KUD or private company as processor in the production of dried chips and cassava flour.
(2) The village or subdistrict selected must be a cassava production center at the district or provincial level.
(3) Readiness of the KUD or processor to produce cassava flour and collect dried chips from farmers or their groups.
(4) Sufficient infrastructure such as transport and marketing facilities.

Infrastructure needed to implement project

Implementing the project brought together all aspects of production, processing, and marketing of cassava chips and flour. The most appropriate available technology was tested in real-life situations. Table 4 shows the space and installations required for a village-level processing operation.

Problems encountered were variable product quality in farmer-processed chips; inadequate quality control for both chips and flour; inadequate communication between farmers and processors; difficulties in developing handling systems for poor quality chips; and difficulties in establishing the social organization needed for processes that produce marketable products. Operational research directed toward resolving these problems was an essential component of the project.

Supply and sorting area. Fresh roots are supplied to this area and higher quality roots separated for processing. This area is most important at the processor level where it is a part of the processing area. The roots are weighed, graded, grouped,

Table 4. Infrastructure required by three models of the cassava chip and flour agroindustry, Indonesia.

Infrastructure	Model 1 (individual farmer)	Model 2 (farmers' group)	Model 3 (processor as nucleus)
Supply and sorting area (m^2)	4-8	10-16	20-30
Processing area (m^2)	10-15	30-40	300-500
Drying area (m^2)	20-30	80-100	800-1,000
Storage room for chips (m^2)	8-12	20-30	200-300
Storage room for flour (in tons of flour)	-	-	1,000

and sequentially processed according to their time of harvest. Ideally, all roots should be processed no later than 24 h after harvest.

Processing area. In models 1 and 2, roots are peeled, washed, soaked, chipped, and pressed in this area. In model 3, milling and packing are also done here. The area must have a brick or plastered platform with sufficient slope to provide good drainage and easy cleaning. In East Java, the size of the processing area for model 3 is about 4 x 10 m. In model 1, processing is usually done in the backyard or kitchen. Some model 2 systems have an area set aside, usually in a group leader's house or "office."

Drying area. Sun drying is the most appropriate and cheapest method for all three models to dry chips. The drying area must be completely exposed to the sun, with a small shaded area where workers can spread wet chips on to trays before moving them into the sun. The area is completed with a wooden or bamboo rack to hold the trays during drying. Ideally, trays are 0.8 x 2 m and can carry 7-10 kg of wet chips, depending on the weather. Model 3 has a drying area capacity of 6,000 kg.

Storage room for chips. Once dried, chips are packed and stored in a room. The platformed floor is covered with wood or bamboo to protect the chips from direct contact with the concrete or brick floor. In model 3, the storage room is also used to keep products collected from farmers or farmers' groups. The chips are stored until milled or sold. In models 1 and 2, no special area is set aside for storing chips, which are stored with other field produce in the central house.

Storage room for flour. The floor area for storing cassava flour is about the same as for chips. Cassava flour is more compact than chips, and therefore requires less space. Cassava flour is stored only for short periods before being sold.

Processing procedures

The procedures followed by the village plant to process cassava flour are root handling, peeling, washing and soaking, chipping, pressing, drying, milling, and packing.

Root handling. The characteristics and quality of the eventual cassava products influence the way roots are handled by farmers. Root handling includes time and methods of harvesting, transport from the field, and storage. For a good quality product, roots should be processed in less than 24 h after harvest.

Peeling. Roots are peeled manually with a knife or traditional peeler, usually by women. Peeled cassava yield is about 70%-80%, that is, 15-20 kg/ha per person.

Washing and soaking. Peeled cassava is washed thoroughly, then soaked overnight (for high-cyanogen cultivars), or for a few minutes (low-cyanogen cultivars) while waiting to be chipped. Soaking should be done in excess water to inhibit browning and reduce cyanogenic (HCN) potential where necessary.

Chipping and pressing. Peeled and soaked roots are then chipped into 0.2-0.5 x 1-5 cm chips. The wet chips are then placed on a tray and pressed with either a screw or hydraulic press. Pressing reduces moisture, drying time, and HCN content, especially for high-cyanogen cultivars. It is optional for low-cyanogen cultivars.

Drying. Pressed chips are spread out on a bamboo or aluminum tray, which is put on a rack in direct sunlight. Pressed chips take between 14 h and 2 days to dry, whereas unpressed chips take 2-3 days. The faster the drying, the better the quality of chips.

Packing and milling. Dried chips are packed in double plastic bags, which are tightly sealed. They can then be stored for about 6 months. Chips from models 1 and 2 are taken to the processor, whereas in model 3 the chips are milled to flour, using a 60-80 µm mesh. Usually the flour is packed into thick plastic bags (0.5-1.0 kg) or into double sacks (25 kg).

Implementing the agroindustrial model for cassava flour production

Processing operation system. The agroindustrial model follows a “foster-parent” system in which the big Government-owned corporations are appointed as “foster parents.” The “foster-parent” company was supported with equipment and technical skills through collaboration with research and development institutes. For example, SURIF/CRIFC and PT Petro Aneka Usaha collaborated in founding an agroindustrial system for cassava flour in Ponorogo district.

At the village level, an agroindustrial model has been developed in which the farmers or farmers’ groups produce dried chips as an intermediate product. The “foster parent” is the milling plant, which produces cassava flour. In this system, farmers produce dried chips two to three times a week, depending on their capacity and the weather. The farmers or farmers’ groups pool their dried chips before sending them to the cassava flour plant.

The plant mixes the chips collected from this source with those from other sources at a ratio of 60% to 40%, respectively. These mixed chips are either suitably stored or milled for distribution, or sent to the distributor.

This system has advantages for both the plant and the farmers. The plant guarantees that all chips produced by the farmers will be accepted and bought. Advantages for the plant are that its equipment, especially the mill, operates at optimal capacity; it obtains, indirectly, drying areas from farmers and farmers’ groups; labor efficiency is optimized; and plant operational time is longer during the cassava off-season because of its stock of dried chips.

Material, energy, and production cost analysis. Material conversion value in cassava flour processing is influenced by root size and peel, cassava variety, and equipment used. Large, easily peeled roots mean higher yields. Table 5 indicates the material conversion in each processing step (Damardjati et al., 1991). The average yield of dried chips is 34% and of flour, 32%. Screw pressing results in a slightly higher yield than hydraulic pressing. The root cyanogenic potential strongly influences yield recovery of dried starch. Normally, high-cyanogen cultivars contain more starch than do low-cyanogen cultivars.

At the time of the study, labor wages were 2,500 rupiahs/day (exchange rate was Rp 2,126 = US$1.00). Based on the yield recovery of flour (32%), the total production cost of cassava flour was 18,725 rupiahs/kg.

Economic analysis

Price determination. Standard prices are an important factor in the cassava flour agroindustry, and are usually higher than those of sliced *gaplek*, which are unstable and depend on middlemen. Farmers have no bargaining power. *Gaplek* prices always decrease, especially during peak season. Farmers producing dried chips also face the same problem as do *gaplek* farmers. For example, one factory buys cassava chips from farmers at a higher price (Rp 50/kg more) than the highest price for *gaplek*. Another factory, however, uses a table based on root prices.

Farmers do not readily accept these methods of determining prices. SURIF and the "foster-parent" factory collaborated to determine a standard price for dried chips, which, in 1992, was 270 rupiahs/kg of chips.

Added value for farmer. Traditionally, farmers in Ponorogo district processed cassava roots into *gaplek*. Table 6 compares the added value of chips with that of *gaplek* for farmers, showing that the added value for farmers was 2,175 rupiahs/100 kg of roots.

Table 5. Yield recovery in cassava flour processing calculated from 500 kg of fresh cassava.

Form of cassava	Number of samples	Processing recovery (%)		Average conversion value
		Min.	Max.	(%)
Peeled roots	15	73	83	80
Soaked and peeled roots	12	74	88	82
Wet chips before pressing	15	70	88	80
Pressed chips:				
Screw press	6	61	68	65
Hydraulic press	6	61	66	
Dried chips:				34
Screw press	6	29	37	
Hydraulic press	6	22	37	
Flour	15	30	34	32
Dried starch (byproduct)	9	2	5	

SOURCE: Damardjati et al., 1991.

Table 6. Added value of cassava chips compared with that of *gaplek* for farmers, Ponorogo district, Indonesia, 1992[a].

Item	Costs in rupiahs[b]	
	Dried chips	*Gaplek*
Labor costs:		
Peeling	1,000	1,000
Chipping and drying	1,000	
Equipment hire (Rp 10/kg dried chips)	300	
Total costs	2,300	1,000
Product price	270	125
Income from product	8,100	5,625
Economic profit	5,000	4,625
Economic income + wage	7,800	5,625
Added income	2,175	0

a. Calculations based on 100 kg of roots, *gaplek* yield at 45%, chips yield at 30%, 1992 prices of *gaplek* at Rp 125/kg and *sawut* (chiplets) at Rp 270/kg, and equipment hire for dried chips at Rp 10/kg.

b. Exchange rate: Rp 2,126 = US$1.00 (January 1994).

Consumer Acceptance and Marketing

Survey on consumer acceptance

Consumer acceptance and market assessment studies were conducted in two locations with different consumer characteristics: Purwakarta region and Ponorogo district, both in East Java. The inhabitants of Purwakarta and Karawang districts in the Purwakarta region do not produce cassava and eat it infrequently. In contrast, Ponorogo district is a major cassava-producing area where the inhabitants eat cassava as the second staple after rice.

A survey was first carried out on 115 families in Purwakarta region and 124 in Ponorogo district to discover the acceptability of cassava flour, its use, and consumer preferences. In both areas, more than 80% of respondents did not know of the product but, when it was introduced, received it well (more than 84% of respondents).

More than 50% of respondents from both areas used the cassava flour to make traditional foods. Respondents from Purwakarta region also tended to like cookies and cakes (Table 7), whereas those from Ponorogo district tended to prefer traditional foods. One reason for the difference may be location: the Purwakarta region is larger and most respondents were more educated and skilled in food products.

Consumers' use of cassava flour. Cassava flour can be used as a substitute flour in wheat-based products. For household consumption, most respondents preferred to process it into either (1) traditional foods, (2) cakes, (3) cookies, or (4) *krupuk*, a cracker-like product. Table 8 shows the basic ingredients and processing.

More than 50% of respondents used cassava flour to bake traditional foods because they were simple to prepare, were familiar, and the other ingredients readily available. The respondents' different income levels were reflected in the different preferences for food types prepared from cassava flour (Table 9). About 43% of high-income consumers preferred to process cassava flour into cake as compared with 21% of medium- and 29% of low-income consumers who tended to prefer traditional foods. Table 10 gives examples of traditional foods in which cassava flour can be used as a substitute for other flours.

Consumer acceptance for long-term consumption. The survey also assessed consumer acceptance of and the kind of food products made from cassava flour in the long term. Most respondents used as much as 50% cassava flour mixed with another flour such as wheat, tapioca, or rice for traditional foods (e.g., *bala-bale*, fried banana, and *putu ayu*) and cakes. For cookies and *krupuk*, relatively little was used (Damardjati et al., 1992), although as much as 60% substitution with cassava flour, resulting in good quality cookies, has been reported (Damardjati et al., 1992). Cassava flour and tapioca (cassava starch), mixed at a ratio of 1:3, respectively, have been used in *krupuk*, resulting in an acceptable product (Suismono and Wheatley, 1991).

In a cooking trial, carried out by 115 respondents, cassava flour was accepted by about 84% and rejected by about 15%. The respondents' average demand for cassava flour is about 5-7 kg/month. The group that purchased the most had a medium income. Most consumers would

Table 7. Consumer preferences for cassava products in Purwakarta region and Ponorogo district (%), Indonesia.

Product	Consumers in Purwakarta region[a]		Consumers in Ponorogo district[a]	
	Like	Dislike	Like	Dislike
Traditional foods	57.0	3.3	59.7	12.1
Cookies or crackers	13.1	0.9	8.9	0.8
Cakes	37.8	1.8	9.7	8.9

a. Number of households surveyed was 115 in Purwakarta and 124 in Ponorogo.

SOURCES: Damardjati et al., 1993; Martini, 1992.

Table 8. Processing and ingredients of products processed from cassava flour, Indonesia.

Type of ingredient and process	Traditional foods	Cookies	Cakes	*Krupuk*
Basic ingredients	Wheat flour Rice flour	Wheat flour	Wheat flour	Tapioca flour
Additional ingredients	Margarine Eggs Cane sugar Vegetables Coconut milk	Margarine Eggs Cane sugar	Margarine Eggs Cane sugar	Cane sugar
Other ingredients	Salt Artificial coloring	Leavening Flavoring	Leavening Artificial flavoring	Salt Spices Flavoring
Process	Steamed, fried, or roasted	Oven-baked	Oven-baked	Steamed before frying

Table 9. Consumer preferences (%) among foods prepared from cassava flour, Purwakarta region and Ponorogo district, Indonesia. Samples given during a consumer-preference survey.

Respondent group	Processed products			
	Traditional foods	Cookies	Cakes	*Krupuk*
Purwakarta region Income group:				
Low (n = 39)	67.6	16.2	29.7	2.7
Medium (n = 46)	75.6	12.2	21.9	2.4
High (n = 30)	53.3	13.3	43.3	-
Ponorogo district:				
Urban (n = 57)	66.7	17.5	15.8	-
Village (n = 67)	76.1	1.8	24.6	-

Table 10. Traditional food products made with cassava flour as substitute flour, Indonesia.

Local name	Cassava flour (%)	Other flour	Brief description
Bala-bale	50	Wheat	Mixture of flour, water, vegetables, and spices. Fried.
Cimplung	50	Wheat	Mixture of flour, water, sliced jackfruit, and salt. Fried.
Nagasari	70	Maize	Mixture of flour, coconut milk, sugar, salt, vanilla, maize flour, and cooked. Filled with sliced banana and wrapped in banana leaf. Steamed.
Jongkong	50	Rice	Dough of flour mixed with coconut milk and salt, and cooked. Filled with sliced palm sugar and thick coconut milk. Wrapped in banana leaf. Steamed.
Ongol-ongol	65	Wheat	Mixture of flour, water, and sugar, and cooked. Formed, cooled, and sliced. Served with grated coconut.
Dodongkal or awug	100	-	Cooked flour with water and salt. Dough filled with shredded palm sugar. Served with grated coconut.
Biji salak	100	-	Small balls made from flour dough and cooked. Served with sweet coconut milk and sliced jackfruit.
Bika Ambon	35	Rice	Two mixtures of flour, egg, "fermipan," and coconut water. One mixture worked into a dough. Other mixture cooked with sugar and coconut milk until oily. The two mixtures then combined and baked.

process cassava flour into traditional foods (41.7%) and cakes (21.7%).

Marketing problems. During the several years of establishing and developing the cassava flour agroindustry, marketing was the first problem faced. Cassava flour was unknown and the market had to be developed. Farmers and farmers' groups depend heavily on a mill to act as nucleus for collecting and buying chips. The mill sells mostly to food industries. But the market for processed cassava products is small, with the consequence that the plant (nucleus) becomes overstocked in chips and flour. Operational management also becomes a problem.

One company which has expanded its cassava processing operations is PT Mariza, a food company that produces snack foods and cakes. This company has increased its monthly output of cassava flour by over 200% since 1991 (Figures 3 and 4).

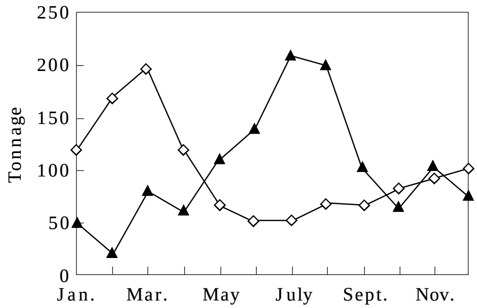

Figure 3. Trends in purchasing chips and selling cassava flour by PT Mariza, Indonesia, 1991. (◇ = purchasing; ▲ = selling.)

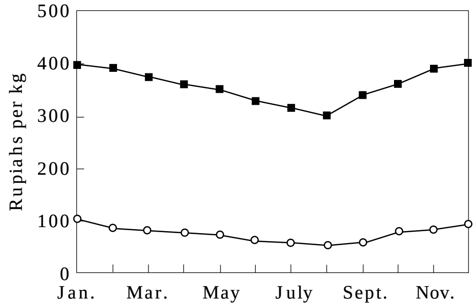

Figure 4. Trends in prices of cassava roots and cassava flour in transactions carried out by PT Mariza, Indonesia, 1992. (■ = flour; ○ = roots.)

Future Development of the Cassava Flour Agroindustry

Interrelationships among determinants in the agroindustry's development

The main interacting participants in the cassava flour agroindustry are (1) farmers or farmers' groups, (2) KUD or processor, (3) factory and distributors, and (4) consumers (Table 11). The four determinants are (1) policy, (2) infrastructure, (3) participation, and (4) technology.

Farmers or farmers' groups. Basic policy needs to be constructed at farmer level. An example is determining a suitable floor price for chips, to motivate farmers in processing. Small farmers should obtain credit from banks through simple procedures and flexible guarantees. They should also receive extension and training in skills for developing both the cassava flour agroindustry and its processed products.

KUD or processor. The KUD or processor also expects simple procedures and flexible guarantees when obtaining credit from banks. To ensure the agroindustry's continuity at village level, each small industry's share of production should be protected. Chip prices should also be sufficiently competitive.

The village KUD or processor has a relatively low management capability, needing guidance in its operational management. Simple and easily installed equipment with locally available spare parts is to be preferred. The demand for such equipment will provide opportunities for local workshops.

Industry and distributor. To speed up distribution of cassava flour to consumers the market share of the flour at distribution level needs to be determined through the National Food Authority (BULOG). A 10% share from the total distributed by BULOG will suffice to warrant cassava flour marketing. The increased agroindustry will speed up the development of cassava products, the prices of which will be heavily influenced by their quality.

Consumers. Even with BULOG's intervention in distributing cassava flour, distributors and retailers are responsible for making it readily available to consumers. Three methods are to undercut the prices of other flours, promote through mass media, and encourage food and catering industries to increase their use of cassava flour as a raw material in processing food.

Supporting activities

To support efforts in developing the agroindustry, certain governmental policies are urgently needed. These would help improve quality; create a production environment advantageous to processors, distributors, and farmers; and change consumer attitudes toward cassava. These policies are:

(1) *Price and distribution policies.* Price and distribution policies for cassava products (cassava flour and chips) of defined levels of quality can encourage increased production and improved product quality. The ensuring of cassava raw material supplies requires an established distribution mechanism.

    The continuous distribution of cassava flour throughout the year will encourage farmers to increase cassava production and ensure a continuous supply for processors. BULOG is expected to play an important role in the distribution system, which will then develop

Table 11. Matrix correlation of determinants, by participating groups, in the cassava flour agroindustry, Indonesia.

Determinant	Subject			
	Farmers or farmers' group	KUD[a] or processor	Industry	Consumer
Policy	- Basic price of chips - Easy credit - Credit ensured - Assurance flexibility	- Credit ensured - Assurance flexibility - Protection of production share - Basic price of cassava flour	- Cassava flour marketing at distributor level, BULOG[b] controlled - BULOG[b] as "foster-parent," but no market monopoly	- Good distribution through BULOG[b] intervention - Ceiling price
Infrastructure	- Extension - Training - Credit for chipping equipment - Market implementation	- Guidance in operation management - Credit for equipment and operational costs - Market information	- Facilities for promoting processed cassava products - Facilities for credit	- Promotion through mass media - Improvement role of service - Products from cassava flour
Participation	- Price expectation - Processing efficiency - Added value in processing	- Price expectation - Processing efficiency	- Continuity of chips and cassava flour supplies - Standard quality of chips and flour - Export promotion	- Competitiveness of taste and flour packaging - Attractive packaging - Can be mixed with other flour
Technology	- Simple and easily installed equipment - Spare parts available - Relatively cheap	- Simple and easily installed - Spare parts available - Labor intensive	- Efficient	- Serving technique

a. Koperasi Unit Desa (village union cooperative).
b. BULOG = National Food Authority, Indonesia.

SOURCE: Adnyana et al., 1991.

through the self-supportive nature of the existing market.

(2) *Support for industrial and export diversification.* Developing cassava flour processing plants is the main step toward supporting the development of cassava industries in general. The consistent demand for raw material for cassava flour production has already increased at farmer level. To develop, these industries need support in providing an environment that will attract investors.

Quota restrictions have already severely limited the possibilities of increasing the traditional export of dried cassava (chips and pellets). But export volumes can be expanded for nontraditional commodities such as fructose, sweets, sorbitol, and modified starch. Various food products with potential as export commodities have already been formulated with cassava flour as raw material.

(3) *Extension* should be aimed at various levels of the community: farmers and their families, processors, and other groups. Extension materials should be structured according to each targeted level of the community.

(4) *Campaigns and promotion.* The Government can help change the community's attitudes toward cassava through such activities as promotion, extension, expositions, and cooking festivals.

(5) *Community uses of cassava flour.* Catering services and bakeries would be the major consumers of cassava flour, especially by substituting for wheat flour in their products. Other promoters include governmental and semigovernmental organizations such as KORPRI, Dharma Wanita, and Dharma Pertiwi; nongovernment organizations, including social and professional organizations; and the mass media.

Conclusions

Developing the cassava flour agroindustry represents for Indonesia an alternative for diversifying cassava products. It can potentially increase farmer incomes, extend marketing, support food diversification, reduce wheat imports, and contribute to the development of various chemical and food industries. Cassava flour processing requires the development of techniques and equipment for peeling, washing, soaking, drying, chipping, pressing, and milling.

The cassava flour agroindustry can be structured on three models, according to capital, capability, knowledge, and distribution systems of the raw material. These models are based at farmer level (model 1); farmer group level (model 2); and mill or plant belonging to a group of private companies or cooperatives as a nucleus in the processing and marketing system (model 3). The mills act as processors of intermediate products, that is, dried chips, from models 1 and 2 to be processed into cassava flour as final product. An economic feasibility analysis showed that a cassava flour agroindustry is feasible at the village level when it is based on the three models being structured into a system.

Cassava flour can be processed into four groups of food product: traditional foods, cookies, cakes, and *krupuk*. The higher the income and education of the household mother, the more likely that cassava flour will be accepted for use in traditional foods and cakes. As many as 84% of consumers would accept cassava flour, and most of these could buy 4 to 7 kg of cassava flour per month. With promotion and improved supplies, the flour therefore has a high potential to develop a niche in urban markets, especially as supplement to cereal flours.

Marketing is still a major constraint to expanding the cassava flour agroindustry. The PT Mariza's successful expansion was supported by its ability to diversify its products and markets. Governmental support and policy making is still necessary to create a favorable production environment and improve quality at every step of the production system to match market demands.

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CHAPTER 13

WORLD PRODUCTION AND MARKETING OF STARCH[1]

*Carlos F. Ostertag**

Introduction

Starch production is a major world agroindustry, with a volume of around 33 million tons per year, and a value of US$14 billion (Jones, 1983; Marter and Timmins, 1992; Titapiwatanakun, 1993) (Table 1). Starch is extracted primarily from cereals and roots through processes that separate fiber and protein.

Demand for starch is influenced by its versatility. Almost all major industries use starch and, as a result, industrialization normally coincides with a significant increase in the demand for this raw material (Lynam, 1987c).

Three main classes of starch-based products exist: unmodified or native starches (UMS), modified starches (MS), and sweeteners. Modified starches are those in which one or more of their physical and chemical properties have been changed slightly (Jones, 1983).

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1. No abstract was provided by the author.

Main Starch Sources

Starch is extracted from maize, sweetpotatoes, cassava, potatoes, wheat, rice, sorghum, sago palm, arrowroot, and bananas (AVEBE, 1989; Jones, 1983). Developed countries grow most of the world's maize, potatoes, and wheat, whereas developing countries grow most of the sweetpotatoes and cassava. For example, China produces almost 85% of world's sweetpotatoes (Rhem and Espig, 1991).

These starches differ from each other in their granule forms and sizes, contents of amylase and amylopectin (the two types of glucose polymers present in starches), swelling capacities (i.e., capacities to absorb water), and gelatinization temperatures (Jones, 1983).

In the early 1980s, 77% of world's starch was estimated to derive from maize (Jones, 1983), mainly because 91% of the starch produced in the USA, the world's largest producer, was from maize (Farris, 1984). The increase in yield per hectare, from 2.4 t in 1950 to 7.6 t in 1986, contributed significantly to this cereal's importance (Lynam, 1987c).

Table 1 shows the relative importance of different starch sources. Two reasons for the

Table 1. Estimated world starch production (1992) (thousand tons)[a].

Region or country	Raw material						Total	Percentage of world production
	Maize	Sweet-potato	Cassava	Wheat	Potato	Other		
North America:	13,450	-	-	200	55	20	13,725	41
USA	13,200	-	-	50	50	20	13,320	40
Canada	250	-	-	150	5	-	405	1
Latin America	1,000	-	330	-	-	-	1,330	4
European Union	3,400	-	-	1,400	1,200	-	6,000	18
Ex-USSR and Eastern Europe	300	-	-	-	300	-	600	2
Africa	-	-	20	-	-	-	20	<1
Asia:	3,020	4,165	3,442	165	400	30	11,222	34
China	-	4,000	300	-	-	-	4,300	13
Japan	2,500	120	-	150	400	-	3,170	10
Thailand	-	-	1,800	-	-	-	1,800	5
Indonesia	-	-	800	-	-	-	800	2
India	200	-	350	-	-	-	550	2
Vietnam	-	-	90	-	-	-	90	<1
Philippines	75	-	17	-	-	-	92	<1
Malaysia	-	-	70	-	-	-	100	<1
Taiwan	45	15	15	15	-	30	90	<1
South Korea	200	30	-	-	-	-	230	1
Australia	50	-	-	300	-	-	350	1
Total	21,220	4,165	3,792	2,065	1,955	50	33,247	100
	64%	13%	6%	6%	6%	0%	100%	

a. Includes modified starches and sweeteners.

SOURCES: Estimates based on Jones, 1983; Marter and Timmins, 1992; Titapiwatanakun, 1993.

decrease in the proportion of maize starch (64%) are (1) the table includes estimates by Marter and Timmins (1992) of starch production in China, derived mainly from sweetpotato, which Jones excluded in the 1983 estimate; and (2) Thailand has greatly expanded cassava starch production recently (Titapiwatanakun, 1993).

Production of maize starch is concentrated in the USA, Japan, and the European Union (EU). Asia is the chief cassava starch producer, primarily Thailand, Indonesia, China, and India; with Brazil, in Latin America, also an important producer. Production of potato starch is centered in the EU (especially Holland), Japan, and Eastern Europe. China accounts for almost all of the world's production of sweetpotato starch, whereas the EU, Australia, and Canada dominate wheat starch production (Table 1).

The maize starch produced in Japan is derived mainly from imported U.S. maize, as used to be the case for the EU. This region now locally produces 99% of its maize requirements for starch production (Leygue, 1993). Local maize-processing capacity has displaced native starch sources such as rice, sweetpotatoes, potatoes, and cassava. For example, in Japan, in 1962, 80% of the starch produced was derived from sweetpotatoes and potatoes. But this share fell to 20% by 1982, displaced by U.S. maize. The main reason was that Japanese starch was used mostly for producing sweeteners, a category for which the technology for maize wet-milling is very advanced (Lynam, 1987c).

Simplified Classification of Starch-Based Products

Starch is a versatile raw material compared with other carbohydrates. Native starch can be modified or chemical derivatives obtained from it by using relatively simple processes. Starch is dispersible in cold water and has a higher reactivity than the highly polymeric cellulose. Starch is also highly susceptible to partial or total hydrolytic degradation by acids or enzymes, yielding oligomeric or monomeric products, which, in turn, can be further modified or used to obtain chemical derivatives not possible from cellulose or sucrose. Starch can also be separated into amylose and amylopectin, and can be used in solvolysis with alcohols (Koch and Roper, 1988) (Figure 1).

A simple way to classify starch-based products is as follows: UMS, MS (e.g., dextrins, pregelatinized starches, and oxidized starches), starch derivatives (e.g., esters, ethers, and cross-linked starches), and sweeteners (glucose syrups, high fructose syrups, dextrose, and maltodextrins) (Jones, 1983; Koch and Roper, 1988). Starch derivatives and sweeteners are used primarily in the food industry.

Native starches are marketed dry, under different grades for human and industrial consumption. Most developing countries produce only this type of starch, except for those with Corn Products Corporation (CPC)

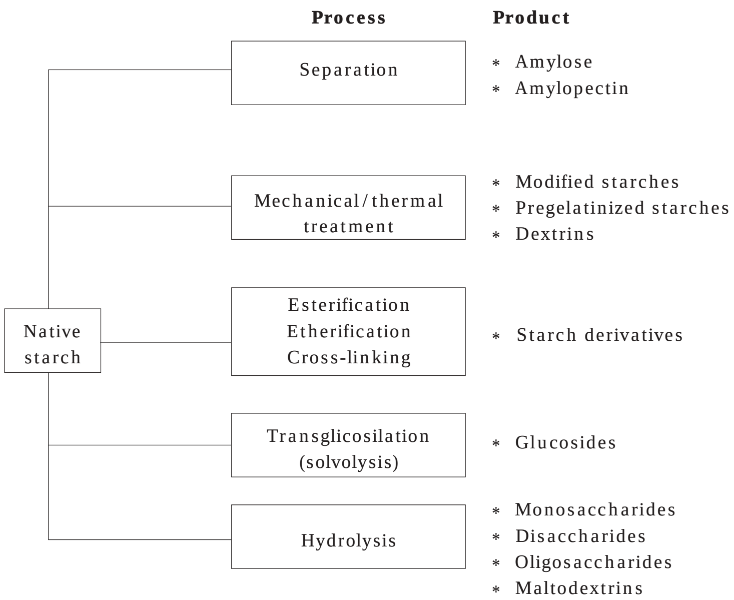

Figure 1. Starch-based products. (After Koch and Roper, 1988.)

subsidiaries, which also produce MS (Jones, 1983).

Modified starches are those that have been changed slightly in one or more of their physical and chemical properties. Modification aims to adjust the product to the particular needs of a client or to imitate a competitive product. The range of modifications and processes is vast and complex but can be summarized as follows:

(1) Pregelatinized type by feeding a starch suspension on to a heated rotating drum.
(2) Dextrin type from dry chemical treatment.
(3) Wet chemical treatment, including thin boiling and oxidized starches.
(4) Other modifications, including the use of catalysts and cross-linking and etherifying agents (Jones, 1983).

The term “sweetener” refers to products such as glucose syrup, high fructose syrup (HFS), and dextrose. Sweetener production is based on acid or enzymatic hydrolysis of starch. Chemically, glucose and dextrose are synonymous, but, commercially, “dextrose” is used to describe the pure crystalline product and “glucose syrup” products obtained from incomplete starch hydrolysis (Jones, 1983).

By subsequent complex processing, based on enzyme action, HFS can be obtained. This product has grown substantially in importance, particularly in the USA, where it was introduced in 1968. Usually based on maize, it is known as high fructose corn syrup (HFCS) in the USA and as isoglucose in Europe (Jones, 1983).

Main Starch Producers

Table 1 shows that starch production in the USA, almost exclusively maize starch, accounts for 41% of world production. Asia has become an important starch producer, contributing to more than one-third of world production. The major producers are China (sweetpotato), Japan (maize), and Thailand (cassava). Asian starch is extracted mainly from sweetpotatoes (38%), cassava (31%), and maize (28%). Although maize starch is from U.S. maize, the other starches are obtained from local raw materials.

No exact records of sweetpotato starch production in China exist but, according to Marter and Timmins (1992), the volume could be about 4 million tons/year. Processing is at household level in villages and the starch is used primarily for making noodles, a traditional oriental food.

Starch consumed in Japan can be categorized as (1) starch obtained from local crops such as potatoes and sweetpotatoes, (2) starch derived from imported raw materials such as maize and wheat, and (3) imported starches, such as cassava, sago, and potato starches (Jones, 1983).

The EU produces nearly 18% of world starch, principally from maize, wheat, and potato. France alone accounts for one quarter of this volume (Leygue, 1993). Obtaining starch from wheat flour through wheat-washing technology (gluten separation) has increased since 1983, with an annual growth rate of 15%. This source has displaced maize starch to a significant extent (Leuch, 1990). Starch production in the EU has grown at an annual compound rate of 4.4% during 1981-1990 (Koch et al., 1993).

Latin American starch production accounts for 4% of world production and consists of maize and some cassava starches. Brazil dominates the production of both starches.

The starch industry mostly supplies its own domestic markets. In 1980, excluding internal EU trade, only 4% of world production (600,000 t/year) was estimated to be exported (Jones, 1983). Since then, starch production has expanded to such an extent in Thailand and China, that exports have more than doubled, to almost 1.5 million tons. Almost 70% of Thai starch is exported, mainly to the USA, Japan, and Taiwan (Titapiwatanakun, 1993).

International trade is concentrated in UMS, mainly from Thailand, China, Indonesia, and Brazil, and consists chiefly of cassava and sweetpotato starches (Jones, 1983; Shuren and Henry, 1993; Titapiwatanakun, 1993). The major markets for exported starch are Japan, Taiwan, the USA, and the EU (Jones, 1983).

The recent high growth rate of the starch industry in Thailand is worth studying. The Thai starch industry has confronted two limitations: first, the high tariffs for starch imports in almost all nations except the USA; and the second, competition with the pellet and chip export market for raw material. The domestic EU price for cereals determines local root prices, which is why roots for the starch industry are so expensive. The starch industry, in turn, has to compete with the low international maize prices (Lynam, 1987c).

But the establishment of export quotas for Thai pellets to the EU in the early 1980s lowered domestic prices of cassava roots and led to a doubling of cassava starch exports (Lynam, 1987c). Titapiwatanakun's study (1993) of the impact of the recent 29% reduction in the domestic price of cereals in the EU indicates that the farm price of local roots will decrease in Thailand, liberating raw material for producing cassava starch. Thai cassava starch exports have increased at an annual growth rate of about 14% since 1975 (Atthasampunna, 1990; Lynam, 1987b; Titapiwatanakun, 1993); for example:

Year	Exports in tons
1975	145,000
1980	248,000
1985	497,000
1989	646,000
1991	1 million

Current Starch Markets

In most countries, starch consumption is highly correlated with production. Exceptions are those countries where starch production is primarily export-oriented (e.g., Thailand and China) or where starch is imported (e.g., Taiwan and, to a lesser extent, Japan).

General uses

Starch has one of the widest ranges of end-uses of any product derived from vegetable sources. It is a good source of carbohydrate but in the food industry it is used mainly as a thickener, filler, binder, stabilizer, or texture improver. Some examples of these uses are in canned and powdered soups, instant desserts, custard powder, sausages and processed meat, sauces, bakery products, confectionery, and ice cream. Sweeteners such as syrups are used for soft drinks, pastries, and canned goods; this segment has shown the most growth in the last 25 years. Edible starch is also used in the pharmaceutical and brewing industries (Jones, 1983).

The industrial uses of starch and starch products are numerous. Among the most important are in the paper and board industry (printing papers, coated papers, corrugated board), adhesives (labels, laminating, gummed paper, tape), textiles (sizing, finishing), oil-well drilling (drilling "mud"), dye stuffs, and the building, metal, and chemical industries (Jones, 1983).

Uses in the USA

More than 95% of the starch currently used in the USA is obtained by wet milling maize. In 1992, 48% of the wet milling output was destined for HFCS production, 25% for glucose and dextrose, and 27% for actual maize starch (USDA, 1993a). These figures exclude ethanol production based on the wet milling technology but it should be noted that more than 10 million tons of maize were used for this purpose in the USA in 1992 (USDA, 1993a).

Table 2 shows starch production and relative weight for 1980 and 1992 of the main starch-derived products in the USA. The end-use as sweetener is prominent, representing more than 70% of the total. The high growth of the HFCS segment can also be noted for the absolute domination of the soft drink market for sweeteners since 1985 (Claassen and Brenner, 1991). HFCS production is divided into HFCS-55 (containing 55% fructose) with a market share of 58% and HFCS-42 (containing 42%) with 42%.

The use of maize-based sweeteners, especially HFCS, has grown dramatically because of their excellent quality, their usefulness as functional agents in foods, and their lower cost versus sugar (Long, 1985). HFCS is a direct substitute for sugar in every area except dry mixes or wherever a nonhygroscopic sweetener is required, as is the case for hard candy and table sugar (Long, 1985).

The end-uses for UMS and MS in the USA (1980 data from Jones, 1983) include:

(1) Paper industry (60% of UMS and 50% of MS), including for sizing, coating, and corrugation.
(2) Food industry (20% of UMS and 20% of MS), including for ingredients in cookies and convenience foods (e.g., instant soups, desserts, and frozen dinners).
(3) Other important industrial users are the brewing, pharmaceutical, and adhesive industries (20% of UMS) and the textile industry (30% of MS).

Table 2. Production of the principal starch products in the USA in millions of tons (mill. t)[a].

Product	1980		1992	
	(mill. t)	(%)	(mill. t)	(%)
Maize starch				
HFCS[b]	1.91	31	6.00	45
Glucose syrup	1.86	30	2.90	22
Dextrose	0.41	7	0.60	4
Subtotal sweeteners	4.18	68	9.50	71
Unmodified	1.18	19	2.20[c]	16
Modified	0.68	11	1.40[c]	11
Other	0.06	1	0.10[c]	1
Other starches (e.g., wheat, potato)	0.07	1	0.12	1
Total	6.17	100	13.32	100

a. Excludes ethanol production derived from wet milling maize.
b. HFCS = High fructose corn syrup.
c. C. F. Ostertag, 1993, unpublished data.

SOURCES: 1980 data: Jones, 1983.
1992 data: Farris, 1984; Kirby, 1990; USDA, 1993a.

Almost 100% of the starch-based production of sweeteners is destined for the food industry. More than 70% of the HFCS production is used by companies producing carbonated soft drinks; 90% of HFCS-55 is used for carbonated soft drinks (USDA, 1993b). Other uses for sweeteners include pastries, canned fruit, dessert dairy products, and dressings and ketchup. Apart from their sweetening properties, they are also useful for controlling hygroscopicity, texture, freezing temperature, and viscosity (Long, 1985).

Uses in the EU

Of the 6 million tons of starch produced in the EU, 54% is used by the food industry and the remaining 46% by the nonfood sector, including paper (19%), chemicals and fermentation (13%), corrugation (7%), and others (7%) (Koch et al., 1993). Other relatively new uses in the EU are for the production of ethanol, plastics, and polymers (Agra Europe, 1990). The annual growth rate of nonfood markets (4.8%) has been greater than the global market (4.4%) (Koch et al., 1993).

Starch is consumed in its native (29%), modified (17%), and hydrolyzed forms (54%). Hydrolyzed starch is used in sweets, beverages, fruit preparations, and pastries (Koch et al., 1993).

Of the 1 million tons of starch employed by industry in the then West Germany (1987), 41% was used for the following product categories: adhesives, pharmaceuticals, paper and cardboard, soap, chemicals, dyes, paints, building materials, and rubber products (Christmann, 1991).

The use of wheat flour in nonfood industries in West Germany increased from 1,000 to 90,000 t during 1980-1987 because of its special chemical properties. At the same time, the consumption of potato starch also increased, whereas that of maize starch decreased (Christmann, 1991). The demand for starch overall in Germany by nonfood industries in the year 2000 is predicted to be between 600,000 and 800,000 t, and for the EU, between 2.5 and 3.0 million tons (Christmann, 1991).

Uses of potato starch

The chief world markets for potato starch, mostly located in the EU, are the following industries: food, paper, textiles, and mineral oil (additives for oil-well drilling) (AVEBE, 1989). In the early 1980s, these uses were distributed in the USA as follows: 33% for paper, as a cationic derivative; 30% in the food industry in native or modified form for preparing soup mixes, puddings, and sweets in general; 19% for adhesives, preferably in dextrin form; and 15% in pregelatinized form as an additive in oil-well drilling. The latter segment exhibits the highest growth rate (Mitch, 1984).

Uses in Japan

In 1980, almost 60% of the starch produced in Japan was for sweeteners, mainly HFCS, derived primarily from U.S. maize, but also from sweetpotato and potato starches. Nearly 15% of the starch was destined for MS production, principally based on imported maize; the main MS produced was oxidized starch. Other important uses were for paper, cardboard, and textiles (7%); fish products such as *kamaboko* (7%); beer (3%); and monosodium glutamate (MSG), a popular flavor enhancer in Asian cuisine (1%). The rest of the starch (12%) was used chiefly for food products (Jones, 1983). Currently, Japan produces almost 2 million tons of HFCS.

Uses in Taiwan

Taiwan is a major importer of starch, principally cassava starch, which, in 1983, was used mainly for preparing maltose for bakery products and sweets and alpha starch for eel feed. Other uses for MS were adhesives for corrugated cardboard, dextrins, ingredients for food products such as noodles, and other uses in the textile and paper industries. Potentially, MSG can be the largest consumer of starch but molasses are normally used. When the price of molasses goes up, cassava starch is preferred (Jones, 1983).

Other Asian markets

Asians tend to use cassava and sweetpotato starch more for industrial uses than for human consumption. For example, the percentage of cassava starch destined for human consumption fell from 65% to 50% between 1966 and 1980 (Ghosh, 1988). In Indonesia, 3% of cassava roots in 1983 were directed toward starch production, whereas by 1988 this percentage had increased to 10% (Damardjati et al., 1990).

Sweetpotato and cassava starches in China have traditionally been used to prepare noodles and MSG. Almost half the starch production is directed to noodles. Of the 200,000 t of MSG produced annually, 90% are prepared from sweetpotato and 10% from cassava starch (Shuren, 1990).

Other industrial uses of starch in China include sweeteners such as glucose syrup (100,000 t/year), medical glucose, maltose, and HFS. Production of HFS is low because it cannot compete with the sophisticated sugar industry (Shuren, 1990). China has also pioneered the production of sophisticated chemical products.

In Thailand, for the 510,000 t of starch consumed domestically, the main markets in 1991 were household use and food (e.g., noodles), 33%; MSG and lysine, 19%; glucose syrup, 15%; paper industry, 9%; textiles, 3%; plywood, 1%; and others, 13% (Titapiwatanakun, 1993). When comparing these figures with 1983 data (Lynam, 1987b), the food and glucose markets present the highest rates of growth—the glucose market did not even exist in 1983. The markets for MSG, lysine, and end-uses in the paper industry, in contrast, have decreased significantly.

Predictions for the year 2001 suggest that the consumption by the food industry will fall to 18%, whereas the share held by MSG and lysine will rise to 27%, and that of the paper industry to 15% (Titapiwatanakun, 1993). Thailand exports MS mostly to Japan.

About 10% of Indonesian cassava production is processed to obtain starch, which is mostly used (65%) to make *krupuk*, a crunchy native food. Another 15% of cassava starch is used for other foods, 10% for textiles, and 3% for glucose (Damardjati et al., 1990; Lynam, 1987a).

Cassava starch in India is mainly used for household consumption and to prepare glucose and dextrins. In the northern states, it is also used in the textile industry (Padmaja et al., 1990).

Cassava starch production in the Philippines is destined chiefly for the food industry and for glucose. Other minor markets include the pharmaceutical, paper, textile, and adhesive industries (van Den et al., 1990).

Uses in Latin America

Starch in Brazil is used for household consumption, and in the food (e.g., as a thickener, stabilizer in processed meat, base for colors and aromas, and in bread making) and pharmaceutical industries. In nonfood industries, it is employed to manufacture adhesives, paper, explosives, and biodegradable plastics (Cereda, 1991; I. C. Takitane, 1992, personal communication).

The market for sweeteners

Of the market segments for starch, that of sweeteners deserves special attention because it has displayed the highest growth in the last 25 years. The birth of enzyme engineering allowed the low-cost conversion of starch to D-glucose and then to a mixture in equilibrium of D-glucose and D-fructose (HFCS) exhibiting the same degree of sweetness as invert sugar from sugar cane or sugar beet.

High fructose corn syrup. HFCS contains from 55% to 90% fructose (a median of 60%) but the most common in the U.S. market are HFCS-55 and HFCS-42. The HFCS-55 is slightly sweeter than sucrose. A fructose with a 97% purity can be obtained from these syrups (Sasson, 1990).

When HFCS was launched in 1968, it immediately captured 30% of the market for sugar in the USA and doubled the amount of starch produced by the maize wet-milling industry (Whistler, 1984). The success of the HFCS resulted from the protection of the domestic sugar industry, reflected by high internal prices, and the lowered price of maize due to yield increases (Lynam, 1987c).

In 1984, 3.5 million tons of HFCS were produced in the USA, almost 1 million in Japan, and 200,000 in the EU (Sasson, 1990). The following year, the main soft drink manufacturers in the USA decided to increase the proportion of fructose syrup from 50% to 100% (Sasson, 1990). Per capita consumption of HFCS rose almost three-fold between 1980 and 1988 (Table 3). The growth rate of the HFCS began to fall in 1985 (The advance of..., 1991) after conquering the soft drink market, the main market for sweeteners in the USA (Claassen and Brenner, 1991).

The annual production of HFCS in the USA in 1992 was 6 million tons, 58% of which corresponded to HFCS-55 and 42% to HFCS-42 (USDA, 1993b). This volume represents 70% of world production, followed by Japan (The advance of..., 1991).

The current world production of HFS, about 8.5 million tons, is concentrated in developed countries. In the EU, the annual HFS production, about 500,000 t, has been voluntarily restricted to protect the sugar beet industry (Coutouly, 1991).

But an increasing proportion of growth is expected in developing countries, which have alternative sources such as cassava, rice, wheat, and sorghum. Currently, starch-based sweetener production is

Table 3. Growth of annual consumption (kg per capita) of caloric sweeteners in the USA (1965-1992).

Year	Sweetener			
	Glucose syrup	High fructose syrup	Dextrose	Sucrose
1965	5.6	0	1.9	44.0
1975	7.4	3.1	2.3	41.6
1980	8.3	7.0	1.6	38.6
1985	8.9	20.0	1.8	29.1
1992	9.6	23.5	2.0	29.3

SOURCES: Farris, 1984; Higley and White, 1991; USDA, 1993b; Whistler, 1984.

growing faster in Asia and Latin America (Claassen and Brenner, 1991). Some countries, like China and Vietnam, already have small HFS industries. But the international sweetener trade is small, with the USA as a net importer—it purchased almost 200,000 t of HFCS from Canada in 1992 (USDA, 1993b).

Glucose syrup. In contrast, processing for glucose syrup is simpler. Hence, its production is widespread, even in the developing countries of Asia (e.g., Thailand, China, India, the Philippines, and Indonesia) and Latin America (in countries with CPC subsidiaries).

Marketing factors. Table 3 shows the growth of per capita consumption of sweeteners in the USA from 1965 to 1992. By 1985, the combined per capita consumption of sweeteners surpassed that of sugar.

The world sweetener market, however, is divided into caloric (e.g., sugar and HFS) and noncaloric (e.g., saccharine and aspartame) sweeteners. Total consumption of noncaloric sweeteners is equivalent, in sweetness, to 8 million tons of sugar, similar to the equivalent HFS production. As a reference, total sugar production exceeds 110 million tons (The advance of..., 1991).

Prices of the different starch-derived sweeteners in the U.S. market in July 1993 were HFCS-55, US$0.52/kg; HFCS-42, $0.47; glucose, $0.33; and dextrose, $0.54. These prices were considered to be high and a reduction was expected in the fourth quarter (USDA, 1993b). Prices respond to the cost of maize and other inputs and to demand, which is high in summer and declines in other seasons. Dextrose is characterized by a high but stable price (USDA, 1993b).

Marketing Opportunities for Developing Countries

According to Jones (1983), trade barriers such as duties, levies, and quotas limit export opportunities, particularly to the EU and Japan. Price competitiveness is the other major factor affecting market prospects.

"Mass" and "specialized" markets must be distinguished: in the mass market most UMS must compete with one another, with the result that the cheapest, assuming acceptable quality levels, enjoy market success.

In contrast, the specialized market is a small segment of the UMS market, where end-users require specific characteristics, such as a certain granule size or pasting temperature, that can only be supplied by one or two particular starches. But, because other starches can be profitably modified to reproduce the desired properties, these modified starches (usually maize or sweetpotato) may gradually reduce the UMS' share in the specialized market. For example, after World War II, much of the USA's cassava starch imports were substituted with cheaper maize starch (Lynam, 1987c).

Future prospects for starch exporters in developing countries vary greatly with regard to the mass market. In the EU, for example, with the current restrictions, the outlook for import growth is nil. In Japan, import growth prospects are limited to achieving the full quota. If the exporter can compete with U.S. maize prices, then considerable potential exists in the USA.

International trade in MS and sweeteners is small. Sweetener exports are limited. Most MS exports correspond to dextrins. Traditionally, developing countries participate little in this trade. The main potential lies in increasing the exports of the already modified cassava starches being produced in the USA, Japan, and the EU from imported cassava starch.

For developing countries, modified starch exports would earn added value and are likely to have easier access to foreign markets. But a high level of technical expertise and a close relationship between modifier and end-user are desirable. Thailand and China are currently increasing exports of MS to Japan.

In view of the uncertain export opportunities, prospective starch producers in developing countries are recommended to concentrate first on their domestic markets, then expand to neighboring markets, before selling on the international market.

The domestic markets for UMS will grow if the UMS-using industries (food, textile, paper and cardboard) develop. Demand for MS, sweeteners, and, in countries where sugar is scarce or expensive, HFS may arise. Other uses for starches are for composite flours and biotechnological applications.

New Market Perspectives for Starch

Because of starch's versatility, new uses arise every year. It is also an excellent example of a renewable raw material. It should be used more widely in the medium and long term, taking into account three aims: (1) to preserve natural resources, (2) to produce biodegradable products that are environmentally friendly, and (3) to reduce agricultural surpluses (Koch and Roper, 1988). Starch-based derivatives can substitute to some extent for petrochemical products, but focus should be given to preparing and synthesizing new compounds with specific and improved properties (Koch and Roper, 1988).

Ethanol

One new compound of high potential is ethanol. In the USA, since the late 1960s, 95% of ethanol has been produced from wet milling maize. Initially, ethanol was used to blend with gasoline at a 1:9 ratio to produce "gasohol." Currently, this blend represents 8% of gasolines sold in the USA. New uses later emerged: as an octane enhancer in gasoline, and as an oxygenate to reduce the environmental pollution of automobiles. In 1992, ethanol production reached almost 1 billion gallons. Ethanol is now not only feasible but will be the predominant energy alternative in the future. The main oxygenate competitor for ethanol is methyl tertiary butyl ether (MTBE) (Hiunok, 1993; Russo, 1993).

Germany and the EU are studying the feasibility of replacing petroleum-derived products with renewable raw materials such as starch, among others. Analyses are being conducted on substituting 10% of diesel and heating oils and 5% of petroleum with renewable raw materials such as starch, and on the greater use of renewable raw materials as fuel (Schmitt, 1988).

Biodegradable polymers

The USA is increasingly concerned with environmental pollution caused by its production processes and the disposal of its end products. This has forced the plastic industry to look for alternative raw materials and to make its products more recyclable and biodegradable (Beach and Price, 1993).

The current use of biodegradable polymers, mostly based on maize, in the USA has been for items where disintegration after use is of direct benefit. Some examples are agricultural mulch films, planting containers and protectors, hay twine, surgical stitching, medicine capsules, and compost bags. Agricultural pesticide firms are also examining the use of starch-based polymers to encapsulate products (Beach and Price, 1993).

Markets for biodegradable polymers in the USA are food packaging, nonfood packaging, personal care and medical products, and other disposable products. But because the U.S. Government has not regulated the use of biodegradable packaging for food, the key market in the near future will be for nonfood packaging. By 1992, biodegradable polymeric resins had captured 0.06% of the market for plastic resins used by the nonfood sector, representing 2.3 million kg of a total of 3.6 billion kg (USDA, 1993a).

Biodegradable polymers compete in the market for plastic materials and resins, whose composition in the USA (1992) was low-density polyethylene (19%), high-density polyethylene (16%), polyvinyl chloride or PVC (15%), polypropylene (13%), polystyrene (8%), and more than 18 additional materials account for the remaining 29% (Beach and Price, 1993).

Vegetable adhesives

Environmental concerns in the USA over synthetic adhesives have spurred new starch-using technologies destined mainly for the packaging market. Starch-based adhesives are usually less expensive than synthetic adhesives and are free of the unpleasant odors of some animal glues. In 1990, the USA consumed about 4.5 million tons of adhesives, of which 40% were natural. Maize starch dominates the market for natural adhesives with an annual consumption of 1.6 million tons (USDA, 1993a).

Organic chemicals

Agricultural products are increasingly considered as alternative raw materials for organic chemicals. Within the common ground shared by agricultural and chemical industries, a new industry, labeled “green refinery,” may result. The starch industry competes with that of glucose syrup to supply fermentation substrata. Of the possible biotechnological processes, the most viable in the short and medium terms involve producing energy, fermentation products such as amino acids and other organic acids, biodegradable plastics and surfactants, antibiotics, and biocatalysts (Malerbe, 1990).

China has pioneered the development of refined chemical products such as sorbitol, mannitol, oxalic acid, gluconic acid, acetic acid, and ethylene. Sorbitol is used to manufacture vitamin C, for toothpaste, cosmetics, and paints. Mannitol is used to produce polyester and plastic foam, and is also used medically as a plasma expander (Ghosh, 1988; Shuren, 1990).

Large-scale, bioprocess technology already has had a significant impact on the use of starch for producing citric and lactic acids. Improved fermenting processes have been developed for producing butyric, succinic, and propionic acids (Zeikus, 1993).

Food

Previously, starch was appreciated mainly for its nutritional value as a source of calories. Currently, it is also valued for its functional properties related to human health. For example, resistant starch, as does fiber, helps stimulate digestion, and plays a role in the prevention of colon cancer. Fat substitutes such as maltodextrins and complex carbohydrates help reduce caloric intake (Koch et al., 1993).

Other novel starch-based products include solid glucose and fructose, new combinations of starch and fiber, and modified maize and cassava starches used to replace lactic protein in processed meat and yogurt.

Other uses

Other examples of new or expanded markets include systems for controlled release of chemicals, coating agents, surfactants, plasticizers, and sequestrants based on starch (Doane, 1993).

Figure 2 divides the potential industrial (nonfood) use of a range of new starch-derived products into five categories. Figure 3 summarizes both current and future uses of starch-based products.

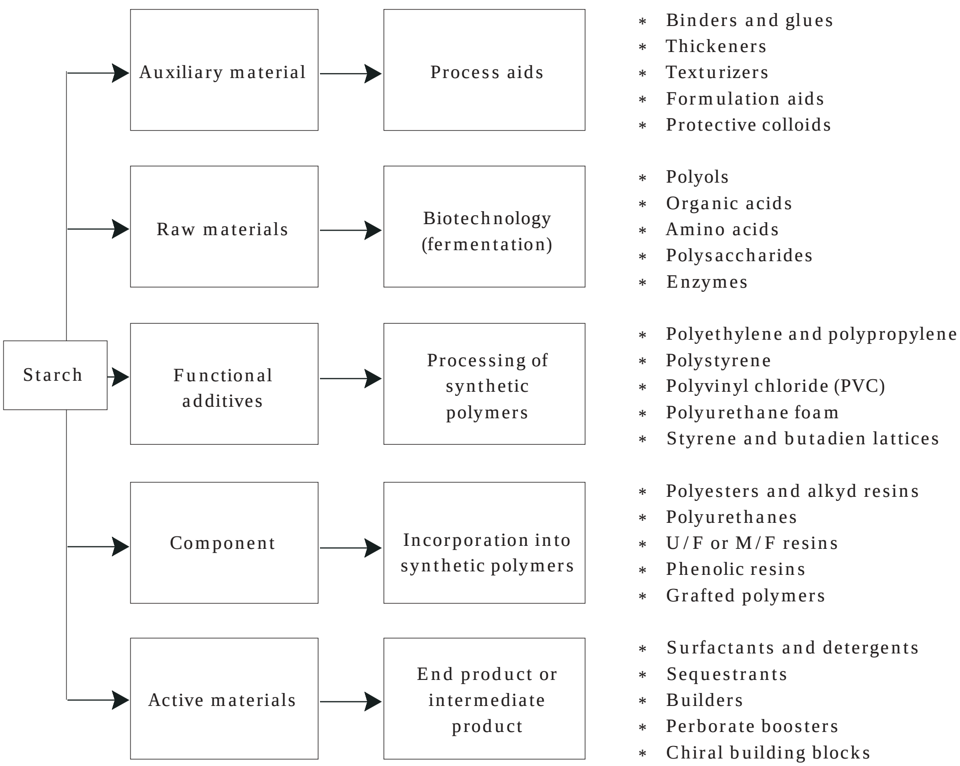

Figure 2. New categories of nonfood industrial uses for starch. (After Koch and Roper, 1988.)

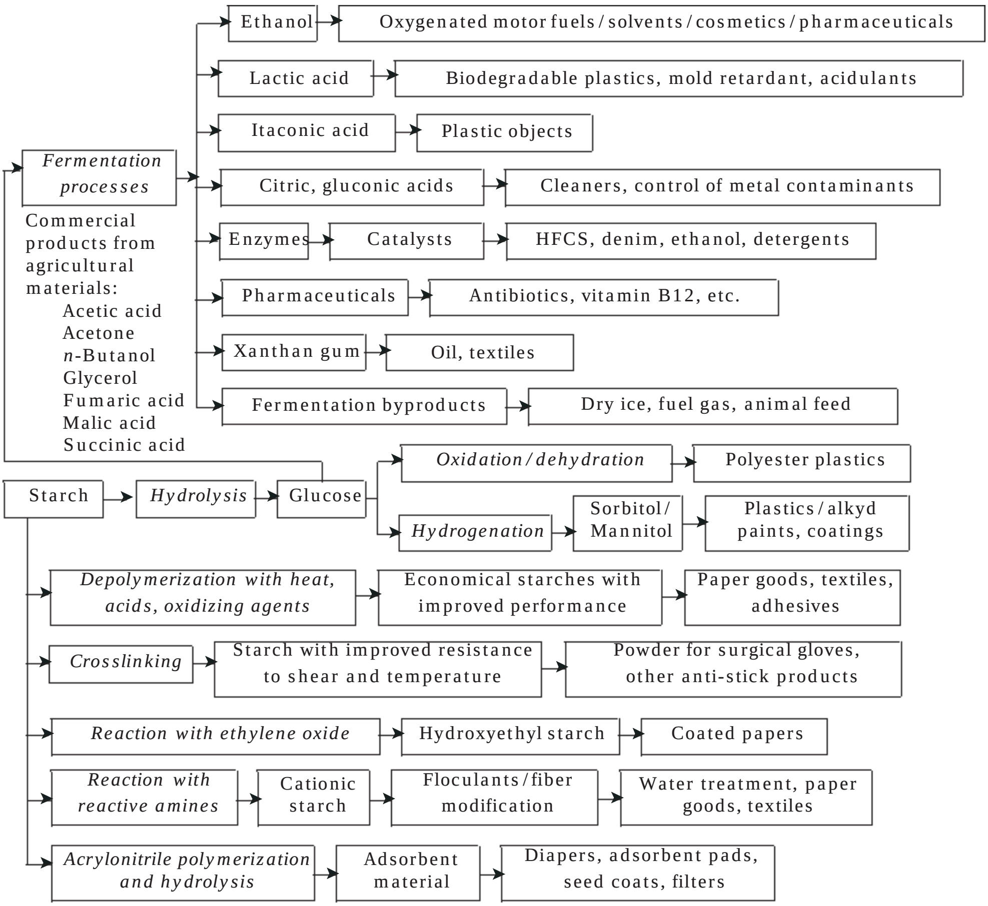

Figure 3. Current and future starch-based products (with processes in italics). (After Parker, 1993, personal communication.)

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Session 3:

Physicochemical Studies of Flours and Starches

CHAPTER 14

THE ROLE OF COMMON SALT IN MAINTAINING HOT-PASTE VISCOSITY OF CASSAVA STARCH

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Abstract

The amylographs of starch and flour from three cassava varieties were determined in salt (NaCl) solutions of 0%, 2.5%, 5%, and 7.5% concentrations. The salt increased the pasting and peak viscosity temperatures. Peak viscosity differed with variety, and increased with salt in some cases, but was reduced to below that of the control in others. Salt also reduced the extent of retrogradation of starch, compared with the control.

Introduction

The average Ghanaian housewife knows that, if a family member is late for the evening meal of *fufu*, she must add salt, pounding it into the cassava paste (or plantain or cocoyam). This practice helps prolong the elasticity of the pounded paste, which otherwise will harden, and, in some cases, become watery.

For industrial starches, certain additives are often used to modify starch properties to make them suitable for particular end products. Tipples (1982) pointed out that, in wheat starch, these additives affect its gelatinization properties. Additives include sugars, syrups, various ions, and some bread ingredients. He cited the study of Hester et al. (1956) on the effect of sucrose on the pasting characteristics of several starches. They reported that:

(1) The temperature of the initial rise in paste viscosity increased for most starches, indicating a delayed swelling of granules.
(2) The temperature of maximum viscosity of starch pastes was lower than, or did not reach, 95 °C, indicating less swelling of granules.
(3) Granules disintegrated less.
(4) The amount of soluble material diffusing from the granules was less.
(5) Starch gels became less rigid, and, when high sucrose concentrations were used, gels did not form.

Bean and Osman (1959) investigated the effect of 10 different sugars and syrups on hot-paste viscosity curves and gel strength of 5% maize-starch paste. The maximum hot-paste viscosity increased slightly during gelatinization with concentrations of sugar as high as 20%, but decreased with higher concentrations. Tipples (1982) also cites Medcalf and Gilles's 1966 study

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on the effect of different salts on wheat-starch amylograms. They found that pasting temperature and peak temperature progressively increased, according to the effects of the classical lyotropic anion series (SCN^-, I^-, NO^-_3, Br^-, Cl^-, F^-, SO^-_4). Except for Na_2SO_4 and NaF, the salts studied gave markedly increased starch peak viscosities. Even NaCl concentrations as low as 0.05 *M* resulted in a significant increase in wheat-starch peak viscosity.

Ganz (1965) found that when a suspension of wheat starch was heated in 2.5% (0.43 *M*) NaCl solution in a Brabender viscoamylograph, peak viscosity markedly increased. This increase was believed to be a result of an enhanced maintenance of "granule integrity." That is, the granule swells, or remains intact, over a longer time before fragmenting. The use of salts was therefore suggested as a way of regulating starch swelling.

Our study accordingly aimed to verify the Ghanaian housewife's practice, and to find agreement with the observed effects of additives on starch gelatinization reported in the literature.

Materials and Methods

A previous study had already examined the swelling power and solubility of three cassava varieties that differed in cooking quality (i.e., mealiness of the cooked root, and elasticity and smoothness of the pounded paste).

Results showed that the three varieties differed in granule swelling characteristics. 'Ankra', a good cooking variety, showed a two-step gradual swelling of granules. But neither the variety 91934, which showed a two-step rapid swelling of granules, nor the variety 30474, which showed a one-step slow swelling, had good cooking qualities. The three varieties differed in the strength of the bonding forces between granules (Figures 1 and 2). These three varieties were used in the present investigation.

The concentrations of NaCl solutions used by Ganz (1965) for wheat were adopted. They were 0.43 *M*, 0.86 *M*, and 1.29 *M*, thus giving 2.5%, 5%, and 7.5% salt solutions, respectively. One sample of 35 g (dry basis) of cassava starch was

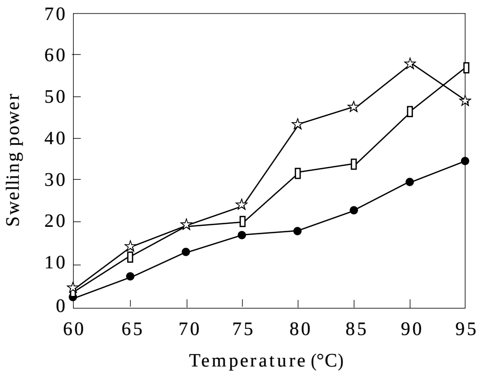

Figure 1. The effect of temperature on the swelling power of starch from three cassava varieties. (☆ = cv. 91934; ▯ = cv. Ankra; ● = cv. 30474.)

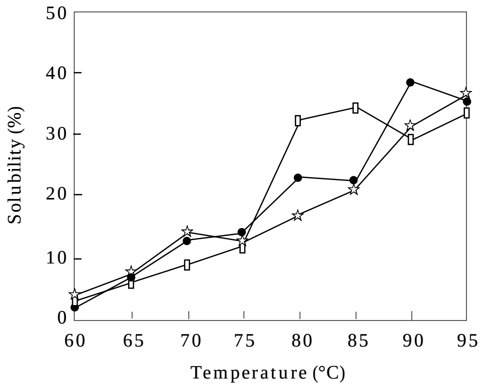

Figure 2. The effect of temperature on the solubility of starch from three cassava varieties. (☆ = cv. 91934; ▯ = cv. Ankra; ● = cv. 30474.)

dissolved in each solution and the standard Brabender procedure followed. The flours were also studied in the same way.

Results and Discussion

The pasting cycles of the starches and flours are presented in Tables 1 and 2 and in Figures 3 and 4, and are discussed below.

Pasting temperature

The addition of salt increased pasting temperature, although the degree of increase varied with variety. These results agree with the findings of Hester et al. (1956) (see p. 123). This

Table 1. Viscosity changes (using Brabender viscosity units = BU) in starch during gelatinization in the presence of common salt (NaCl).

Variety	Salt conc'n	Pasting temp. (°C)	Peak temp. (°C)	Peak visc.	Visc. at 95 °C	Visc. after 1 h at 95 °C	Visc. at 50 °C	Visc. after 1 h at 50 °C
Ankra	0 *M*	74.0	82.0	560	460	260	480	420
	0.43 *M*	75.5	89.0	360	340	150	220	180
	0.86 *M*	74.0	92.0	300	300	160	200	160
	1.29 *M*	79.3	93.5	360	360	200	300	260
91934	0 *M*	74.0	77.0	500	380	145	280	240
	0.43 *M*	75.5	81.5	460	380	30	50	40
	0.86 *M*	77.0	84.5	500	440	60	90	80
	1.29 *M*	77.8	87.5	560	500	100	140	100
30474	0 *M*	71.0	85.0	340	290	140	280	260
	0.43 *M*	78.5	92.0	340	270	110	160	120
	0.86 *M*	81.5	95.0	380	380	180	260	200
	1.29 *M*	81.5	95.0	380	380	260	340	280

Table 2. Viscosity changes (in Brabender viscosity units = BU) in flour during gelatinization in the presence of common salt (NaCl).

Variety	Salt conc'n	Pasting temp. (°C)	Peak temp. (°C)	Peak visc.	Visc. at 95 °C	Visc. after 1 h at 95 °C	Visc. at 50 °C	Visc. after 1 h at 50 °C
Ankra	0 *M*	66.5	75.5	480	480	160	240	250
	0.43 *M*	72.5	80.0	500	380	70	120	90
	0.86 *M*	74.0	81.5	500	400	80	120	100
	1.29 *M*	78.5	86.0	420	400	120	180	140
91934	0 *M*	66.5	75.5	380	40	0	0	0
	0.43 *M*	69.5	77.0	390	100	0	0	0
	0.86 *M*	74.0	80.0	420	180	0	0	0
	1.29 *M*	75.5	81.5	400	220	0	0	0
30474	0 *M*	71.0	78.5	90	60	30	50	50
	0.43 *M*	75.5	87.5	90	80	10	10	10
	0.86 *M*	75.5	84.5	290	170	10	10	10
	1.29 *M*	75.5	86.0	240	190	20	20	20

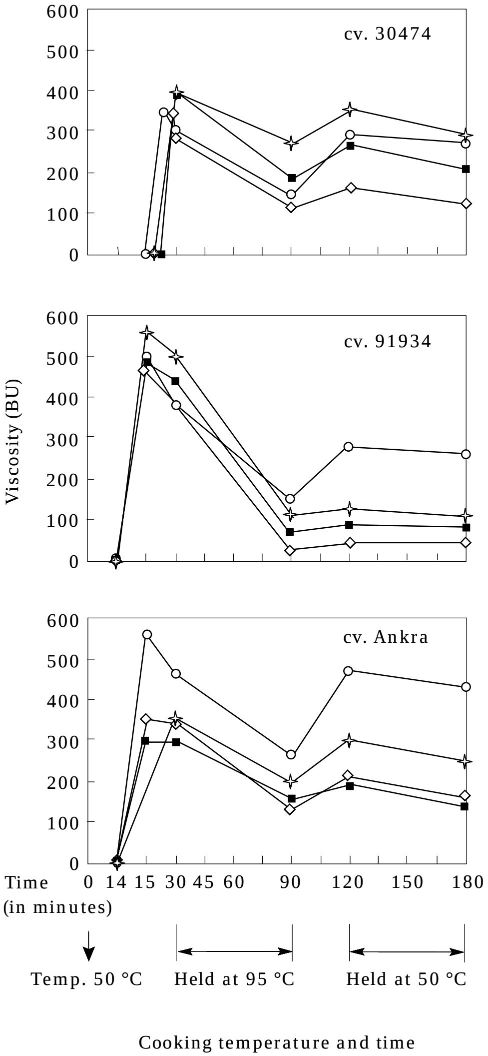

Figure 3. The effect of different salt concentrations on hot-paste viscosity of starch from three cassava varieties. (Salt concentrations: ○ = control; ✧ = 7.5%; ■ = 5%; ◇ = 2.5%.)

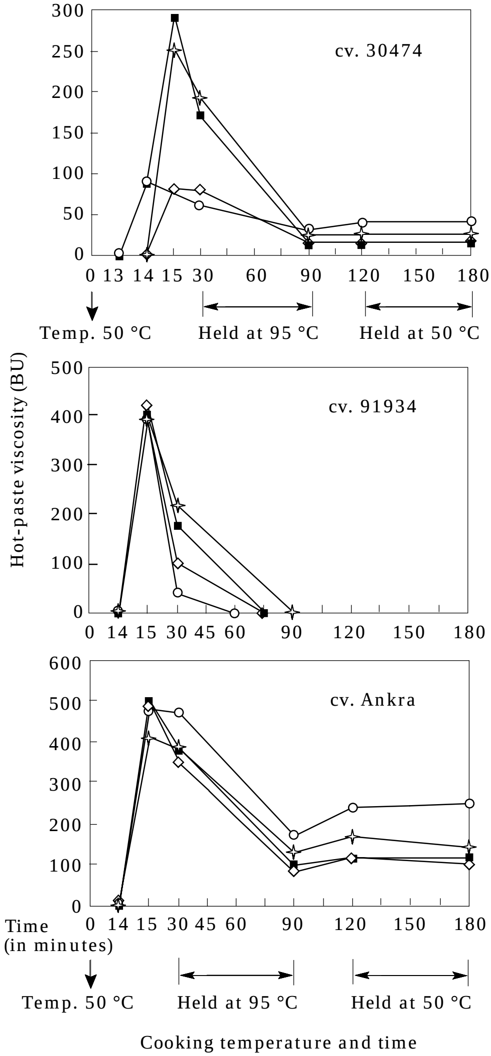

Figure 4. Effect of different salt concentrations on hot-paste viscosity of flour from three cassava varieties. (Salt concentrations: ○ = control; ✧ = 7.5%; ■ = 5%; ◇ = 2.5%.

means that the salt caused a delay in granule swelling.

In all three varieties, adding salt also increased the temperature at which peak viscosity was attained. For example, in '30474', peak viscosity of its starch in 5% and 7.5% salt solutions occurred at 95 °C. The cited Medcalf and Gilles study (1966) found similar results when they examined the effect of different salts on wheat starch amylographs.

Peak viscosity

The effect of salt concentrations on peak viscosity varied with variety. In the flours and starches of '30474' and '91934', salt concentrations of 5% and

7.5% resulted in increases in peak viscosity. These results agree with findings by Medcalf and Gilles (1966) and Ganz (1965), who found that NaCl concentrations of 0.05 *M* and 0.43 *M* significantly increased peak viscosity in starches, for which Ganz (1965) postulated the "granule integrity" hypothesis (p. 124). In 'Ankra', results were slightly different: peak viscosity of untreated starch was far higher than those with salt added, even though peak viscosity increased with salt concentration.

For flour made from 'Ankra', the highest salt concentration of 7.5% had the lowest peak viscosity. Again, this contrasted markedly with the behavior of the other two varieties.

Our results seem to demonstrate that, if starch granules are fragile when swollen, as for variety 91934, adding NaCl may reduce the fragility, but in other cases, as with 'Ankra', salt may inhibit granule swelling.

Salt also affected the temperatures at which peak viscosity could be maintained: at temperatures higher than 95 °C peak viscosity would begin to drop. For all three varieties, even though adding salt did not increase peak viscosity, compared with the control, no differences existed between peak viscosity and viscosity at 95 °C. The reason may be that either the salt increased the temperature at which peak viscosity was attained, or it enabled the swollen granules to remain intact for a longer time before fragmenting.

Retrogradation

"Retrogradation" is an increased rigidity in the starch gel that occurs as starch granules re-associate during cooling, sometimes leading to syneresis, or the release of water. Retrogradation is heavily influenced by the amylose content of the starch. It declines when salt is added. Hence, the Ghanaian housewife, by pounding salt into the pounded paste, is reducing its tendency to retrograde, thus extending its "table-life."

For the three varieties, the extent of retrogradation in pure starch and flour tended to increase as the salt concentration increased, but, except for starch from cv. 30474, the extent of retrogradation was always less than the control. The cited study by Hester et al. (1956) also found that starch gels became less rigid when sucrose was added and that, when high sucrose concentrations were used, gels did not form at all.

Acknowledgments

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CHAPTER 15

AMYLOGRAPHIC PERFORMANCE OF CASSAVA STARCH SUBJECTED TO EXTRUSION COOKING[1]

Z. González and *E. Pérez**

Introduction

In Venezuela, cassava (*Manihot esculenta* Crantz) is consumed preferably fresh but also in other forms. During 1991, 381,069 t of cassava were produced, of which 183,913 t were used for human consumption, including 19,549 t for producing "casabe," a type of cassava bread. Another 38,107 t were used for animal feed, 244 t for export. About 152,428 t were estimated as lost (INN, 1991).

Because starch has multiple uses in the food, pharmaceutical, oil, and textile industries, great interest has arisen in the use of alternative, low-cost sources of this polysaccharide. Starch's functional properties can be modified by different methods. Our study evaluated the effect of extrusion cooking on the amylographic performance of cassava starch.

Materials and Methods

A commercial cassava starch was submitted to extrusion cooking in two Rheocord Torque Rheometers. Model 104 had a single rotating screw that operated at 90 rpm at a temperature of 150 °C, with a 25% sample moisture content. Model 3000 had double, co-rotating screws that also operated at 90 rpm, but at temperatures of 100 and 150 °C, and with 10%, 21%, and 25% sample moisture contents.

Starch suspensions at 6.88% (w/w dry basis) were prepared. These were heated at a rate of 1.5 °C per minute in the bowl of a Brabender amylograph (model A.V. 40, 60-cycle), from 30 until 90 °C. Suspensions were maintained at this temperature for 30 min and then cooled at the same rate to 50 °C, at which they were maintained for 30 min more. Water absorption capacity, solubility, and swelling power of both extruded and native starches were determined by Schoch's method (1964).

Results

Table 1 shows the most important parameters of the amylograms obtained. The initial gelatinization temperature of starches extruded at 25% moisture content (61.5 °C) and

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1. No abstract was provided by the authors.

Table 1. Effect of extrusion cooking on the most important parameters used in cassava starch amylography.

Parameter[a]	Sample			
	Native starch	Extruded starch[b]	Extruded starch[c]	Extruded starch[d]
Initial gelatinization temperature (°C)	60.8	61.5	55.5	61.5
Final gelatinization temperature (°C)	70.5	77.5	67.5	78.0
Maximum viscosity (V_{max}); (BU)	900	740	860	700
V_{max} temperature (°C)	69.8	77.3	66.8	76.5
Viscosity at 90 °C (BU)	380	520	410	530
Viscosity after 30 min at 90 °C (V90/30); (BU)	40	300	260	290
Viscosity at 50 °C (V50); (BU)	400	480	420	320
Viscosity after 30 min at 50 °C (BU)	420	480	430	380
Stability (V_{max} - V90/30); (BU)	660	440	600	410
Sedimentation (V50 - V90/30); (BU)	160	180	160	30
Consistency (V50 - V_{max}); (BU)	-500	-260	-440	-380

a. BU = Brabender viscosity units.
b. Single-screw, 150 °C, 25% moisture content, and 90 rpm.
c. Double-screw, 100 °C, 10.21% moisture content, and 90 rpm.
d. Double-screw, 150 °C, 25% moisture content, and 90 rpm.

that for native starch (60.8 °C) did not differ significantly. However, initial gelatinization temperature for the sample extruded at 10.21% moisture content by the double-screw extruder was 55.5 °C. Apparently, the conditions under which this last operation was performed favored the access of water to the amorphous zones of the starch granules, causing them to swell faster. Gelatinization therefore began at a lower temperature.

The interval between initial and final gelatinization temperatures was greater in starches extruded at 25% moisture content by both single- and double-screw extruders (about 16 °C) than those corresponding to starch processed by the double-screw extruder at 10.21% moisture content (12 °C) and to native starch (9.7 °C) (Table 1). These results indicate that extrusion partially transformed the starch granule structure and affected the macromolecules. This caused a greater temperature interval in extruded products than in native starches.

All processed samples had lower maximum viscosity (V_{max}) values (Table 1) compared with native starches (900 Brabender viscosity units [BU]). Starches extruded at 25% moisture content by single-screw extruders showed V_{max} of 740 BU and by double-screw extruder, 700 BU. These values were lower than that for starch extruded at 10.21% moisture content by a double-screw extruder, which, in its turn, differed by 40 BU from that of native starch (860 BU).

Maximum viscosities of extruded starches, at 25% moisture content, were obtained at 77.3 (single-screw extruder) and 76.5 °C (double-screw extruder), higher than that corresponding to native starch (69.8 °C) (Table 1). Starch extruded at 10.21% moisture content by the double-screw extruder not only showed the lowest temperature for V_{max} (66.8 °C), but also the lowest gelatinization temperature range (55.5-67.5 °C). This finding probably indicates that, because the extrusion process makes more water available to the amorphous zones of starch granules, gelatinization advanced more rapidly and so reached V_{max} at a lower temperature.

Because no V_{max} value similar to that of native starch was obtained in the samples processed, a certain degree of macromolecule rupture and/or reorganization can be inferred. Although native starch presented the highest V_{max}, its swelling power was not the highest (Table 2). Also, at about 70 °C, the temperature at which V_{max} of native starch was obtained, the highest value of water absorption (24.31 g/g starch) and of swelling power (2.34 g/g starch) corresponded to extruded starch at 10.21% moisture content by the double-screw extruder (Table 2).

These findings suggest that the expansion corresponding to V_{max} of extruded starches was the result of various factors acting together, principally swelling power and solubility. The greatest value of V_{max} of extruded samples thus corresponded to processed starch at 10.21% moisture content in the double-screw extruder, whose swelling capacity was the highest of the starches tested. Extruded starch at 25% moisture content in the single-screw extruder had, overall, the lowest solubility values of the starches, even though it tended to swell less than the starches processed by the double-screw extruder.

Table 2. Effect of extrusion cooking on water absorption, solubility, and swelling power of cassava starches.

Temperature (°C)	Sample			
	Native starch	Extruded starch[a]	Extruded starch[b]	Extruded starch[c]
Water absorption (g/g starch)				
65	2.40	7.40	0.90	0.89
70	15.04	14.46	24.31	19.09
75	23.22	17.74	23.14	-
80	29.47	21.09	29.41	24.27
85	31.77	25.17	37.95	28.49
90	43.41	27.86	38.93	30.41
Solubility (%)				
65	1.90	5.44	9.21	9.11
70	11.48	11.09	17.42	17.50
75	21.57	13.52	16.23	-
80	22.11	16.88	22.20	21.78
85	25.21	19.52	39.79	26.33
90	33.09	21.79	59.87	26.54
Swelling power				
65	0.50	0.83	0.90	0.86
70	0.83	1.54	2.34	1.90
75	1.15	1.80	2.24	-
80	1.29	2.19	2.78	2.32
85	1.53	2.62	3.48	2.66
90	2.04	2.93	3.28	2.55

a. Single-screw, 150 °C, 25% moisture content, and 90 rpm.
b. Double-screw, 100 °C, 10.21% moisture content, and 90 rpm.
c. Double-screw, 150 °C, 25% moisture content, and 90 rpm.

Starch modified at 25% moisture content in the double-screw extruder, despite showing an intermediate swelling ability compared with the rest of the processed samples, had the lowest V_{max}. The reason may have been that its solubility was usually higher at the same moisture content than that of the single-screw extruder (Table 2).

In summary, extrusion tended to reduce water absorption capacity and solubility of samples processed at 25% moisture content by single- and double-screw equipment, whereas the swelling power of all extruded starches increased. However, in starch processed at 10.21% moisture content by the double-screw extruder, solubility tended to increase.

Without exception, all starches had reduced viscosity values at 90 °C in relation to V_{max} and, after 30 min at 90 °C, in relation to the initial viscosity (Table 1). The different starch suspensions showed low stability during cooking, that is, granules were highly susceptible to shearing stress. This was reflected in the positive values of the *stability* index, which is defined as the difference between V_{max} and viscosity after 30 min at 90 °C (Rasper, 1980). Native starch was the least stable during cooking (660 BU), followed by starch extruded at 10.21% moisture content in the double-screw extruder (600 BU), starch processed at 25% moisture content in single-screw extruder (440 BU), and starch processed in the double-screw extruder (410 BU).

Viscosity values at 50 °C of all starches were higher than the corresponding viscosity values after 30 min at 90 °C. This finding suggests that a certain degree of retrogradation occurred in these starches, which could be quantified as a *sedimentation* index, or the difference between the viscosity at 50 °C and that after 30 min at 90 °C (Rasper, 1980). Native starch and starch extruded at 10.21% moisture content by the double-screw extruder presented the same retrogradation tendency (160 BU), and starch processed by the single-screw extruder at 25% moisture content showed the greatest sedimentation (180 BU). The lowest value for this index corresponded to starch extruded at 25% moisture content by the double-screw extruder (30 BU).

Viscosity after 30 min at 50 °C was higher than viscosity at 50 °C, except for starch extruded by the single-screw extruder, whose value remained constant (480 BU). In general terms, all starches showed stability during cooking at 50 °C.

Consistency (the difference between viscosity at 50 °C and V_{max}; Rasper, 1980) increased as a consequence of the extrusion process. Native starch showed a value of -500 BU, while extruded starches showed values of -440 BU (starch extruded at 10.21% moisture content by a double-screw extruder), -260 BU (starch extruded by a single-screw extruder), and -380 BU (starch extruded at 25% moisture content by a double-screw extruder).

Conclusions

Extrusion cooking of cassava starch caused a series of modifications in the starch structure, depending on cooking conditions. The amorphous zones of starch extruded at 10.21% moisture content by the double-screw extruder apparently had greater access to water. This translated into quicker swelling of starch granules and the start of gelatinization for all extruded samples at a lower temperature, although the intervals of gelatinization temperature increased due to the process. Swelling power, stability, and consistency of extruded starches also increased, while V_{max} decreased. This appeared to depend principally on swelling power and solubility, among other factors. In the sample processed at 25% moisture content by the double-screw extruder, the tendency of starch retrogradation was notably reduced.

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CHAPTER 16

IMPROVING THE BREAD-MAKING POTENTIAL OF CASSAVA SOUR STARCH

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C. Brabet**, and *G. Chuzel****

Abstract

Cassava sour starch, fermented for use in bread making, is traditionally sun-dried. Changes in the physicochemical and functional properties of the starch during sun-drying were examined for correlations between these changes and the starch's bread-making potential. Starch samples collected after fermentation and drying were analyzed for their pH, total acidity, and lactic acid. Viscoamylograms were plotted and bread-making potential determined. Results indicated that exposure to sunlight considerably changes the physicochemical and rheological properties of cassava sour starch, correlating directly with bread-making potential. During oven-drying, the lactic acid content remained steady, whereas sun-drying at a similar temperature greatly reduced it, thus augmenting the cassava sour starch's bread-making potential.

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Introduction

Cassava sour starch is a product of traditional rural industry in Latin America. It is used for making breads such as *pandebono* and *pan de yuca* in Colombia, and *pão de queijo* in Brazil; and for industrially processed snack foods (Cereda, 1973, 1991; Cereda and Nuñes, 1992; Chuzel, 1990). Urban markets for sour starch are growing in Brazil (where it is known as *polvilho azedo*) and in Colombia (*almidón agrio*).

Bakers and manufacturers regard swelling power as the main criterion of quality, but this is often unpredictable. Our study aimed to understand how bread-making potential is increased during traditional processing, so we could suggest ways of achieving a better quality sour starch (Chuzel and Muchnik, 1993).

The traditional method consists of wet-process extraction of starch from cassava roots (Pinto, 1978; Ruiz, 1988, 1991). The starch is then stored in 0.5 to 5-t capacity tanks and fermented for 20 to 60 days, according to climatic conditions (temperatures may range from 15 to 25 °C) (Jory, 1989). Lactic fermentation takes place and the starch pH drops to about 3.5-4.0 (Cárdenas and de Buckle, 1980). It is then sun-dried on drying tables (Brazil) or on black plastic sheeting laid on the ground (Colombia).

Both fermentation and sun-drying give the cassava starch its bread-making potential (Chuzel, 1992). Fermentation also causes substantial modifications to the starch's organoleptic and physicochemical characteristics (Camargo et al., 1988; Cereda, 1985; Nakamura and Park, 1975).

Larsonneur (1993) achieved optimal swelling power by exposing thin layers (0.5 to 1 cm) of sour starch to the sun (solar radiation intensity ≈1,200 W/m^2) on sheets of black plastic, and shaking the sheets frequently. In confirmation, Colombian sour starch producers maintain that drying in low levels of sunlight results in poor-quality sour starch with low bread-making potential. Brazilian large-scale manufacturers prefer drying sour starch in the sun (sometimes using 12 km of drying tables) to the various types of driers (e.g., hot air, flash driers, and drum driers) used for producing unfermented cassava starch. Industrial trials have shown that sour starch dried artificially has no significant swelling power.

Sour starch is the main ingredient (mixed with fats or cheese, eggs, and salt) in traditional, high-swelling breads. Such breads contain no wheat flour, nor do they undergo yeast fermentation before baking. Additives are not used and the dough is baked immediately after kneading, with no rising or "proofing" time. Rising, therefore, does not involve a protein-gluten network nor the production of carbon dioxide by yeasts as seen in, for example, the making of French bread (Godon, 1981).

Our study examines how sunlight changes the bread-making potential of cassava sour starch by changing the following physicochemical and rheological properties: pH, total acidity, lactic acid content, and Brabender viscosity. The important role of lactic acid is also demonstrated.

Materials and Methods

Preparing samples

Starch samples were collected from production units at Santander de Quilichao (Department of Cauca, Colombia). Three local cassava cultivars were used: 'Amarga' (referred to as starch A), 'CMC 40' (B), and 'Algodona' (C).

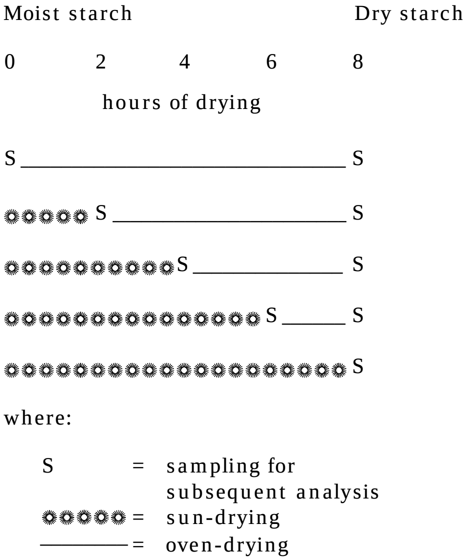
Extracted starch was left to ferment in tiled tanks (0.95 x 0.82 x 0.79 m, capacity 0.5 m^3). The average temperature in the zone was 20 °C, with a small day-night variability of 18 to 22 °C. For starch A, a sample of starch milk (unfermented starch suspension in water) was collected immediately after extraction. A sample of fermented starch was taken after 30 days of fermentation, just before farmers typically initiate sun-drying. The samples were then transferred, in an insulated box, to the CIAT laboratory, frozen at -20 °C, and subjected to drying tests and analysis.

Drying conditions

Sun-drying, on black plastic sheets for 8 h, was similar to traditional sour starch-drying conditions in Colombia (layer 1 to 1.5 cm thick, with agitation every 2 h).

Exposure to sun

Starch samples were sun-dried for different lengths of time (2, 4, 6, and 8 h) and then oven-dried at 40 °C to a final moisture content of about 11%. A control sample was oven-dried only, at 40 °C. This temperature was chosen because it does not cause gelatinization, but is representative of an average daytime temperature in strong sunlight. The sampling plan was as follows:



Rheological and physicochemical analyses

Each of the following analyses was performed in duplicate on starches A, B, and C:

Viscoamylograms. The rheological properties were determined by using a Brabender viscoamylograph. The sour starch was first ground and sieved through a 65/cm (≈150 µm) mesh. An aliquot (500 ml) of an aqueous sour-starch suspension (5% dry matter) was used to plot the viscoamylogram. The analysis unit rotated at 75 rpm; the temperature of the reaction mixture increased steadily at 1.5 °C/min from 25 to 90 °C. The mixture was kept at 90 °C for 20 min, then steadily cooled at 1.5 °C/min to 50 °C; this temperature was kept constant for 10 min. Viscosities are expressed in Brabender units (BU).

Measurement of pH. A 10% (w/v) aqueous suspension was agitated at ambient temperature (20 ± 2 °C) for 30 min and then centrifuged at 15,000 g for 15 min. Supernatant pH was measured.

Assay of total acidity. Total acidity was assayed in 50 ml of the supernatant described above by titration of a NaOH 0.1 N solution in the presence of 1% phenolphthalein-alcohol solution. The results were measured in moles of acid per gram of dry weight of sour starch.

Assay of lactic acid. Cassava sour starch (10 g) was added to 15 ml H_2S0_4 (0.006 *M*) and agitated for 1 min. The suspension was homogenized for 1 min at 24,000 rpm in an Ultraturrax blender, agitated in a vortex mixer for 1 min, and centrifuged at 9,800 g for 25 min. The supernatant was passed through a 0.45 m filter and analyzed by high-performance liquid chromatography (HPLC) as follows: of the filtrate, 20 µl was injected into an Aminex HPX87H column (Biorad), which was controlled thermostatically at 65 °C. Column separation was based on a combination of ion exchange, molecular screening, and hydrophobic exchange. A solution of H_2S0_4 (0.006 *M*) was used as eluant at a flow rate of 0.8 ml/min (Giraud and Raimbault, 1991). The lactic acid peak was detected under ultraviolet light at 210 nm. The results were expressed in grams of lactic acid per 100 g of initial sour-starch dry weight.

Measuring bread-making potential. Procedures for bread making with sour starch and evaluation of swelling power were developed by Escobar and Molinari (1990) and modified by Laurent (1992) and Larsonneur (1993). Sour starch was ground in a mortar and sieved for 10 min through a 65/cm (≈150 µm) mesh. Of this fraction, 85 g (dry weight) was mixed with 100 g of Colombian cheese (Campesino, brand "Alpina") in a Hobart kneading machine operated at low speed (165 rpm) for 1 min. Water was added to obtain a total of 65 ml of water in the dough. It was then kneaded at medium speed (300 rpm) for 2 min. Six 30-g rings of dough with an inside diameter of 2 cm were prepared. These were baked at 280 °C for 17 min and cooled for 2 h at ambient temperature. Each loaf was weighed and its volume measured with a volumeter according to Vanhamel et al. (1991). The specific volume of the bread was then expressed in cm^3/g.

Results and Discussion

Previous tests had shown that freezing had no effect on the viscoelastic properties of starch or on the bread-making potential of sour starch (Larsonneur, 1993). The samples taken after fermentation were therefore frozen to be sun-dried the following day.

The viscoamylograms in Figure 1 show the performances of two subsamples taken from the original starch sample A. One subsample was frozen and the other fermented for 33 days. They were then sun-dried under identical conditions. The viscoamylograms reveal considerable modification of the rheological properties of the fermented sour starch.

Pasting temperature (62.5 °C) and that of maximum viscosity (70 °C) were identical in all the samples. The tendency toward retrogradation (a decrease in viscosity after the peak) increased relative to fermentation, a finding which agrees with those of Nakamura and Park (1975). Peak viscosity decreased in relation to the time allowed for the fermentation—bacterial amylases to break down the large starch molecules (Camargo et al., 1988).

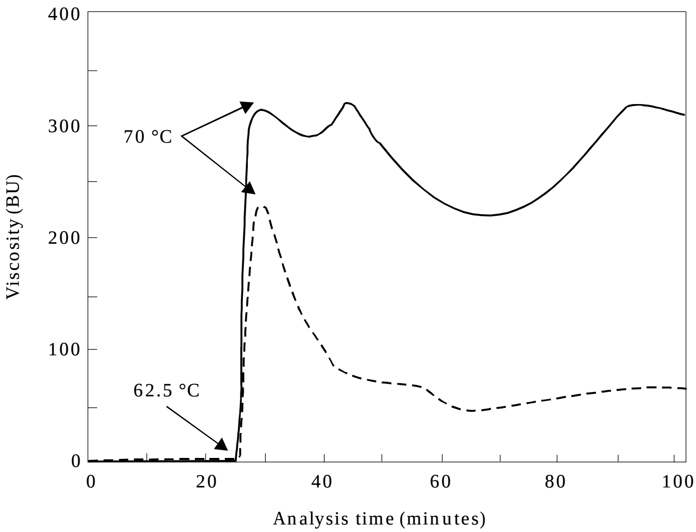


Figure 1. Changes in the rheological properties of starch, extracted from cassava variety 'Amarga', during fermentation. The samples were sun-dried for 8 h before analysis. (——— = unfermented starch; - - - - = starch fermented 33 days.)

The specific volume of the loaves increased from 3.5 to 6.5 cm^3/g for starch A, from 2.0 to 5.8 cm^3/g for B, and from 1.9 to 5.2 cm^3/g for C.

The effect of sunlight

Direct exposure to sunlight (8 h under equatorial conditions) caused substantial changes in the rheological properties of fermented starch A. The viscoamylogram (Figure 2) differs widely from those of the same starch analyzed before drying (wet starch) and after oven-drying at 40 °C. In addition, the two latter viscoamylograms are similar, indicating that oven-drying barely affects the physicochemical properties of sour starch. The sun-dried starch shows a strong retrogradation tendency and a notable decrease in maximum viscosity (from 320 to 220 BU).

Analysis of pasting properties of starch A after 0, 2, 4, 6, and 8 h of sun-drying reveals a rapid increase in retrogradation tendency after about 3 h of exposure to sunlight (Figure 3). In contrast, the decrease in maximum

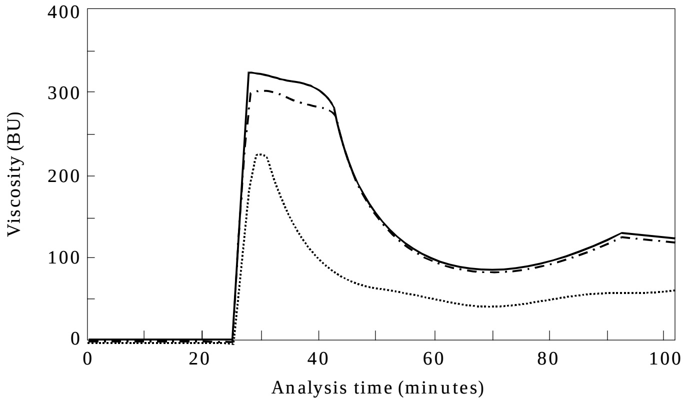


Figure 2. Influence of type of drying on the rheological properties of starch extracted from cassava variety 'Amarga'. Samples were taken after 33 days of fermentation. (—— = wet starch; —·—·— = starch oven-dried 8 h; ·········· = starch sun-dried 8 h.)

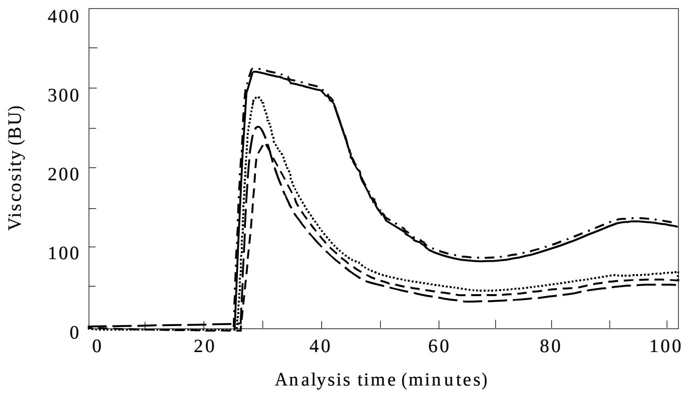


Figure 3. Influence of sun-drying time on the rheological properties of starch extracted from cassava variety 'Amarga'. Samples were taken after 33 days of fermentation. (—— = wet starch; –·– = starch sun-dried 2 h; – – – = starch sun-dried 4 h; — — = starch sun-dried 6 h; ········ = starch sun-dried 8 h.)

viscosity is linear (r^2 = 0.934) against time of exposure to sunlight within the 0 to 8-h range (Figure 4). Because maximum bread-making potential was attained after 3 h of sun-drying (Figure 5), bread-making potential appears to relate more directly to the increase in retrogradation tendency of starch.

In addition, when oven-dried, the same starch showed no increase in bread-making potential. Sun-drying kinetics observed for other cassava cultivars (starches B and C) are shown in Figure 6. They confirm that bread-making potential is acquired during exposure to solar radiation and not after oven-drying.

Significantly, the pH of starch A (sampled after 33 days of fermentation) rose from 3.45 to 3.70 after sun-drying and increased to only 3.50 when oven-dried (Figure 7). Starches B and C similarly increased in pH during sun-drying from 3.48 to 3.55 (B) and from 3.45 to 3.55 (C) (Table 1). Because the pre-drying pH of 3.45 corresponded to the pKa of lactic acid, the medium would have been strongly buffered, with lactic and lactate forms in equal proportions. This small increase in pH during sun-drying (0.25 unit, from 3.45 to

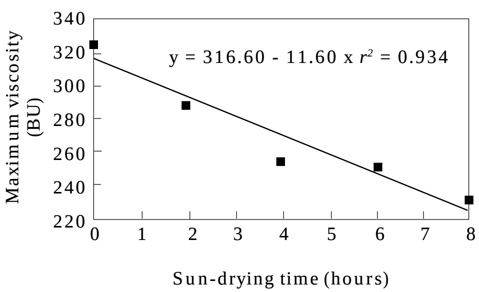


Figure 4. Changes in maximum viscosity of starch extracted from cassava variety 'Amarga' in relation to duration of sun-drying. Samples were taken after 33 days of fermentation.

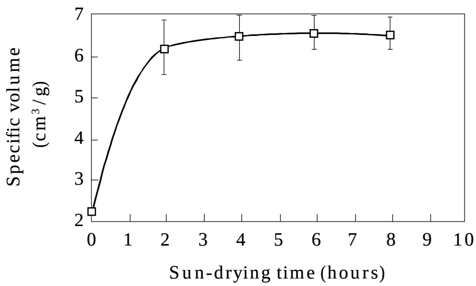


Figure 5. Changes in bread-making potential of starch extracted from cassava variety 'Amarga' in relation to duration of sun-drying.

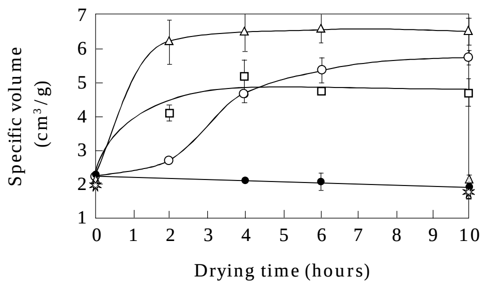


Figure 6. Changes in bread-making potential of starches extracted from cassava varieties 'Amarga' (△) 'CMC 40' (○), and 'Algodona' (□) in relation to duration of sun-drying. All three varieties were also oven-dried (✲ ; ● oven-dried 'CMC 40').

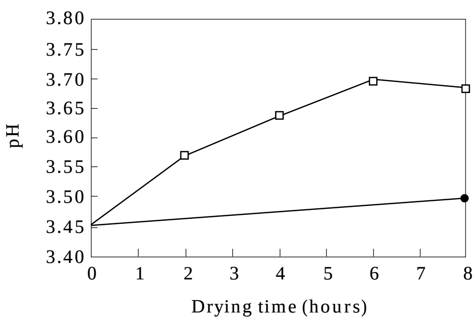


Figure 7. Changes in the pH of starch extracted from cassava variety 'Amarga' in relation to drying time (□ = sun-drying; ● = oven-drying).

Table 1. Acquisition of bread-making potential during fermentation.

Starch	Cassava variety[a]		
	A	B	C
pH of wet sweet starch	6.8	-	-
pH of sour starch before sun-drying	3.45	3.48	3.45
pH of sour starch after sun-drying	3.70	3.55	3.55
Bread specific volume (ml/g) of oven-dried starch	3.5	2	1.9
Bread specific volume (ml/g) of sun-dried starch	6.5	5.8	4.7
Total acidity before sun-drying (10^{-5} mol/g dry matter)	10.5	10.4	7.7
Total acidity after sun-drying (10^{-5} mol/g dry matter)	6.8	9.4	6.7
Lactic acid before sun-drying (10^{-6} mol/g of dry matter)	105	105	76
Lactic acid after sun-drying (10^{-6} mol/g of dry matter)	68	94	66

a. A = 'Amarga'; B = 'CMC 40'; C = 'Algodona'.

3.70, starch A) therefore suggests considerable variation in the proportions of lactic acid and lactate, considering the chemical equation of the buffer solutions (pH = pKa + log base/acid).

This variation during sun-drying can be interpreted either by the transformation of lactic acid into lactate or by the disappearance of the lactic form. The lactic acid assay of fermented starch sample A (Figure 8), sun-dried and oven-dried, indicates that the initial (lactic acid + lactate) content was 10.5 x 10^{-5} mol/g dry weight, which corresponds to the conversion of 1% of the initial starch into lactic acid during fermentation. This decreased to 6.8 x 10^{-5} mol/g dry weight (a decrease of 35%) during sun-drying but remained unchanged during oven-drying for 8 h. Because the oven-drying temperature was similar to that of sun-drying, the disappearance of lactic acid cannot be ascribed to volatilization. Starches B and C similarly produced decreases of 10.4 to 9.4 x 10^{-5} and 7.7 to 6.7 x 10^{-5} mol/g dry weight, respectively. The greater fall in the lactic acid content of starch A (35% against 10% and 13%, respectively) and its higher bread-making potential (6.5 against 5.8 and 4.7, respectively) correlate well (Table 1). The differences observed between starches A, B, and C may be heightened by the diversity of cultivars used, a finding

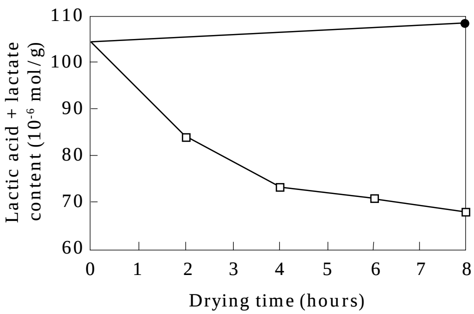


Figure 8. Changes in the lactic acid content of starch extracted from cassava variety 'Amarga' in relation to drying time (□ = sun-drying; ● = oven-drying).

which agrees with that of Chuzel (1992).

The pH increase suggests that lactic acid is consumed in a chemical reaction during sun-drying. The HPLC method used did not permit assay of combined forms of lactic acid and thus did not detect polymerized forms or covalent bonds which might have formed during drying. Detection would be possible after total hydrolysis of the starch.

In classic bread making, wheat gluten forms a three-dimensional network that retains gas bubbles during baking. Baking additives (xanthan gums) are added to non-panifiable flours to increase their bread-making potential (Eggleston, 1992; Godon, 1981). Because starch is the only significant macromolecule in sour starch (no protein or cellulose is present), a three-dimensional network may be formed by a photochemical reaction involving lactic acid and fermented starch. Such a network may account for the acquired bread-making potential of sun-dried cassava sour starch.

Conclusions and Prospects

Fermentation and sun-drying clearly played a role in obtaining sour starch with high swelling power and desirable organoleptic characteristics. At the end of fermentation, the pH was 3.45, following conversion of about 1% of the initial starch to lactic acid. Fermentation gave the starch the necessary physicochemical properties required to later achieve bread-making potential through exposure to sunlight. Fermentation and sun-drying modified the rheological properties of the starch and produced a more marked retrogradation and lower maximum viscosity, together with an increased swelling power. The lactic acid content decreased by as much as 35% during sun-drying only, suggesting a photochemical reaction involving the starch, resulting in the formation of a three-dimensional network that retains gas bubbles during baking and, hence, accounting for the acquisition of bread-making potential by sour starch.

Characterization of the solar radiation involved in this process should lead to the design of drying apparatus that would combine both air-drying and radiation. Such a system would overcome dependence on climate, reduce labor costs and drying space, and reduce losses to wind, poor handling, and external contamination. Brazilian industrialists favor developing an artificial drier to manufacture high-quality industrial sour starch.

A better understanding of the phenomena described in this study should permit the development of modified cassava starch with a high bread-making potential. Such modified starch could be used as an additive (as are xanthan gums) to improve the bread-making capacity of flours which expand little. Furthermore, modified cassava starch could have great potential for the development of gluten-free bread.

Good fermentation practice and solar drying, combined with the use of cassava cultivars specifically chosen for sour starch production, should facilitate the production of high-quality cassava sour starch for which demand exists in bread making and various industries.

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CHAPTER 17

PHYSICOCHEMICAL PROPERTIES OF CASSAVA SOUR STARCH[1]

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Introduction

This chapter describes a collaborative study involving CIRAD, the Institut national de recherche agronomique (INRA), and CIAT. The study investigated the physicochemical bases of baking *pandebono*, a Colombian traditional bread, using cassava sour starch samples provided by CIAT. We evaluated the physicochemical modifications of sour (i.e., fermented) starch during fermentation and drying and tried to relate them with the starch's expansion property and potential for making *pandebono*.

Pandebono dough, a mixture of sour starch, water, and cheese, expands during cooking. This implies that gas is produced, which expands, thus increasing the product's volume (Figure 1). If sweet (i.e., unfermented) starch is used, expansion does not occur, because either no gas is produced, or it escapes from the dough.

If *pandebono* is to expand, as in wheat bread, gas must form and be retained. Retention supposes that the dough has viscoelastic properties that make it gas-tight. Viscoelastic materials in food are generally polymers and polymer networks. They can be proteins such as gluten in wheat bread, nonstarch polysaccharides such as pentosans in rye bread, or exopolysaccharides from microorganisms often added in nonwheat bread recipes (e.g., dextran). Pentosans need oxidative reticulation, and starch gelatinization, to improve their rheological properties. We investigated all these possibilities to explain gas retention in cassava sour starch.

Determining the Presence of Polymers in *Pandebono* Dough

Dufour et al. (Chapter 16, this volume) describe collecting two sets of samples: (1) at different stages of fermentation (0 to 33 days), followed by sun-drying for 8 h, and (2) after complete fermentation (33 days) and at different stages of sun-drying (0 to 8 h). The resulting loaf volumes are shown in Figure 2.

We first determined the nitrogen content of the starch samples, which

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1. No abstract was provided by the authors.

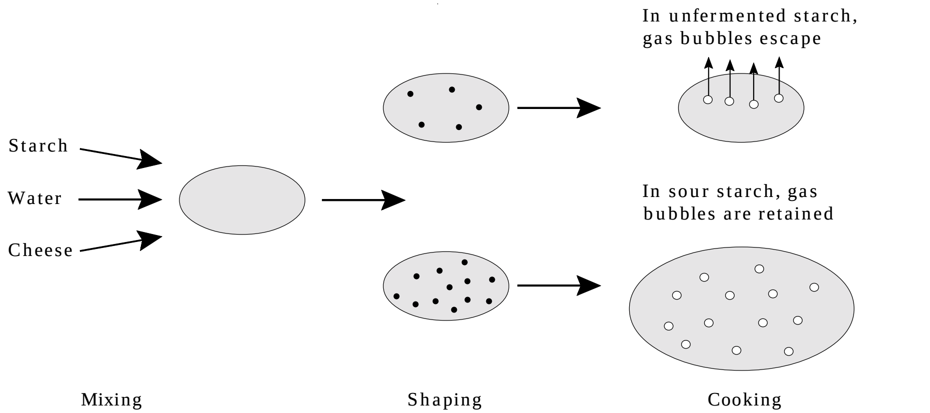

Figure 1. Presumed mechanism of expansion in *pandebono* dough during cooking. *Pandebono* is a traditional cheesebread eaten in Colombia.

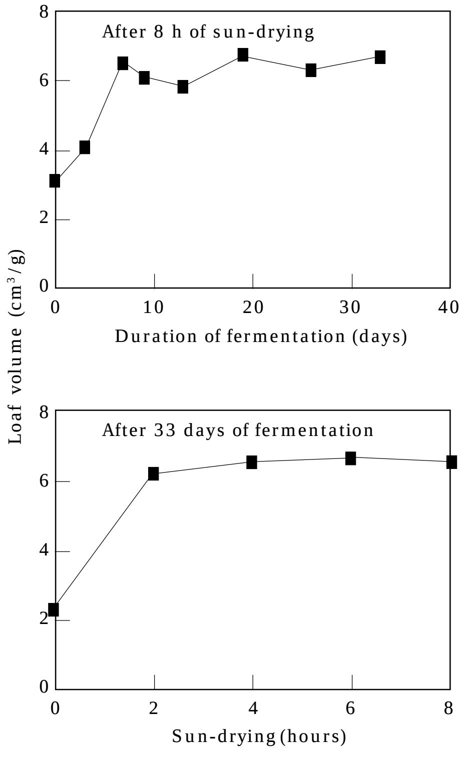

Figure 2. Loaf volumes of *pandebono* (traditional Colombian cheesebread) obtained in two sets of samples. Data from Dufour et al., Chapter 16, this volume.

was very low, ranging between 0.3 and 0.6 g/kg and implying about 0.2% as protein (Figure 3). Fermentation even decreased nitrogen content slightly. Proteins are, therefore, highly unlikely to directly influence the viscoelastic properties of sour starch.

The samples' pentosan content ranged from 6 to 7 g/kg and did not change significantly with the duration of fermentation (Figure 4). These polysaccharides originated from residual fibers of cassava roots, rather than from production of pentosan-like polymers by microorganisms during fermentation.

The molecules of phenolic compounds are efficient oxidative reticulation agents of pentosans, improving their functional properties. They can also absorb ultraviolet light, which greatly increases their activity as oxidative agents. However, we found only traces of ferulic acid, which probably originated from residual fibers. We could not determine whether sour starch contains dextran because this

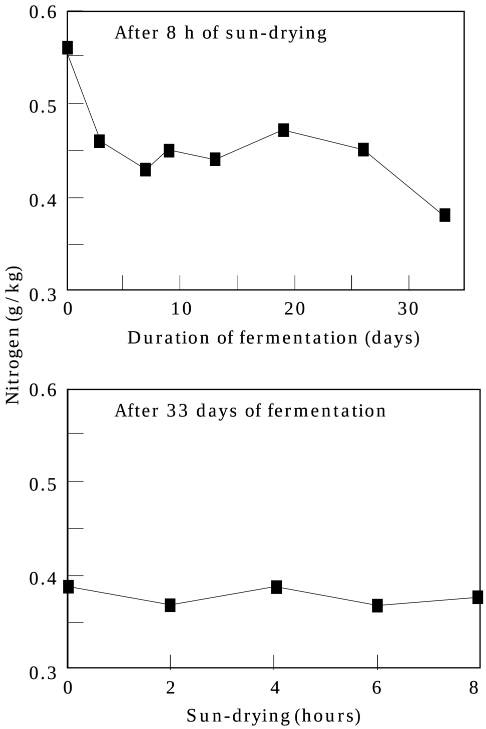

Figure 3. Nitrogen content (g/kg) of cassava sour starch samples.

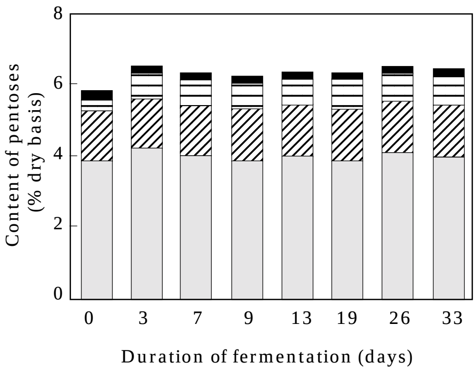

Figure 4. Sugar content of cassava sour starch samples after total acid hydrolysis (glucose is not reported). (■ = xylose; ⊟ = arabinose; ▨ = ribose; □ = rhamnose.)

molecule is very similar to starch and cannot be separated from it.

Protein and pentosan contents of *pandebono* dough are too low to have a significant influence on the viscoelastic properties of sour starch in general, and on gas retention in particular.

The Role of Gelatinization in Gas Retention

Apart from cheese, starch remains the main component of *pandebono* (95%-98% dry matter). We therefore studied the gelatinization and rheological properties of starch to determine whether fermentation and drying modify it in a way that would explain sour starch's ability to expand and retain gas.

We determined starch's thermal properties by using differential scanning calorimetry (DSC). We heated starch at a constant rate of 10 °C/min and measured the heat-flux between 35 to 140 °C. This way we could determine the gelatinization onset temperature (the intercept of base line and tangent to the energy change) and the enthalpy change (the area of heat flux during the gelatinization transition) (Figure 5).

Table 1 gives the results for the most significant samples: unfermented starch, oven-dried sour starch, and sun-dried sour starch. Only the last sample expanded well. The cassava samples did not differ markedly in their thermal properties: for all, gelatinization temperature was close to 60 °C and enthalpy change to 16 J/g. Fermentation and drying did not significantly modify the thermal properties of starch crystallites, thus the specific expansion property of sour starch cannot be explained by changes in crystallites.

Table 1. Thermal properties[a] of cassava starch samples.

Sample of starch	Fermentation (days)		Sun-drying (h)		In pH 4.0 buffer		In water		In pH 7.0 buffer	
	GT	EC	GT	EC	GT	EC	GT	EC	GT	EC
Maize	0	0	0	0	66.2	14.3	-	-	69.0	14.7
Cassava 1[b]	0	0	8	8	60.5	16.6	59.8	16.7	63.9	17.4
Cassava 2[c]	33	33	8	8	60.6	15.5	60.2	16.1	63.5	17.3
Cassava 3[d]	33	33	0	0	60.5	16.1	60.3	16.3	64.0	16.7

a. GT = gelatinization temperature (° C); EC = enthalpy change (J/g dry basis).
b. Unfermented cassava starch.
c. Sour, oven-dried cassava starch.
d. Sour, sun-dried cassava starch.

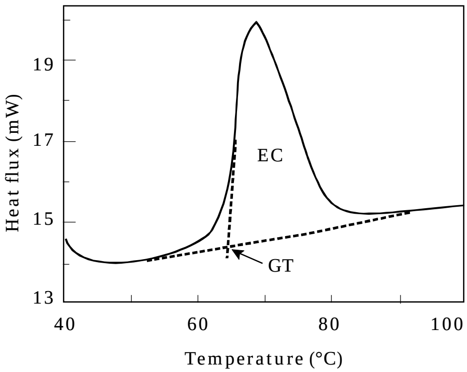

Figure 5. Enthalpy change (EC) and gelatinization temperature (GT) of cassava starch observed with differential scanning calorimetry.

We then characterized the rheological properties of cassava starches. We made viscoamylographic determinations with the Rapid Visco Analyzer, a similar device to the Brabender viscoamylograph. We measured pasting temperature, maximum viscosity, and gelification index (Figure 6).

Our results (Figure 7) confirm those obtained at CIAT (Dufour et al., Chapter 16, this volume):

(1) The pasting temperature is similar for all samples (which matches the DSC measurements).

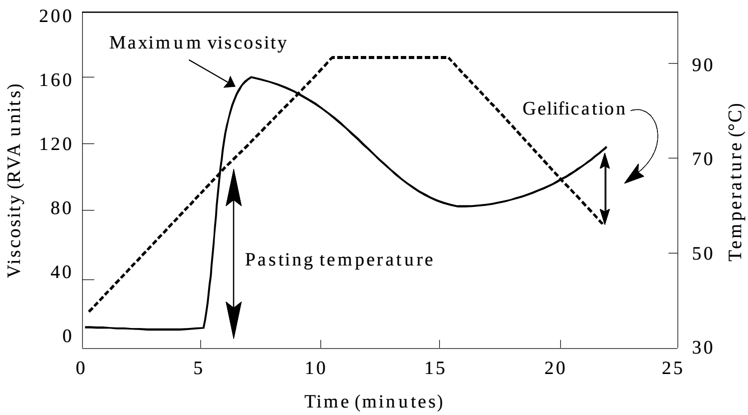

Figure 6. Viscosity profile of cassava sour starch observed by using a Rapid Visco Analyzer (RVA). (—— = viscosity; ------ = temperature.)

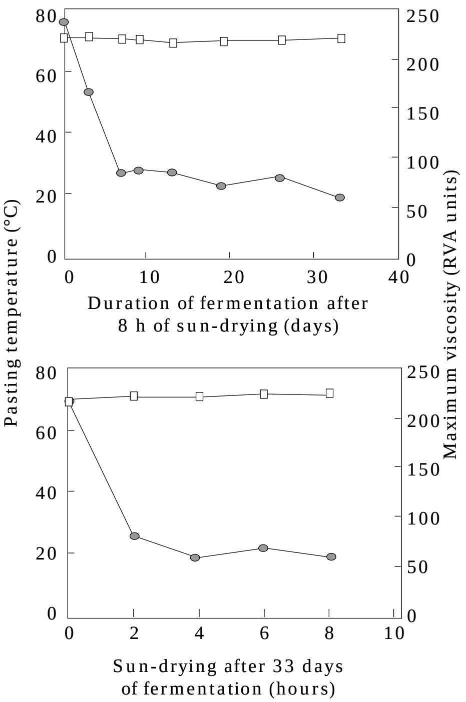

Figure 7. Variation of pasting temperature (-□-) and maximum viscosity (-●-) for two sets of samples of cassava sour starch in phosphate buffer at pH 7.0. (RVA = Rapid Visco Analyzer.)

(2) The maximum viscosity decreased with increased duration of fermentation and sun-drying. This figure seemed related to the loaf volume of *pandebono*: the lower the maximum viscosity, the higher the loaf volume.

These observations were made with samples in a pH 7.0 buffer without amylase inhibitor. However, pH did have a significant effect (Figure 8): in fermented and sun-dried sour starch, which had the best expansion property, maximum viscosity continuously decreased as pH increased from 4 to 10. This phenomenon did not occur for starches unsuitable for *pandebono* making, such as unfermented starch or oven-dried sour starch.

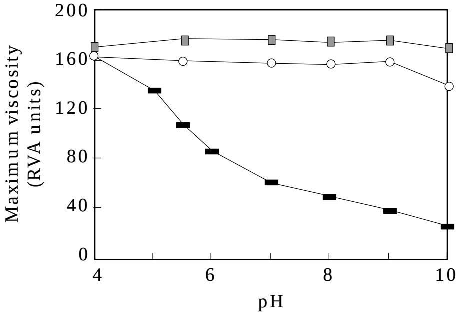

Figure 8. Influence of pH on the maximum viscosity of cassava sour starch samples. (-■- = unfermented, sun-dried; -○- = fermented 33 days, artificially dried; -▬- = fermented 33 days, sun-dried; RVA = Rapid Visco Analyzer.)

Consequently, the maximum viscosity is similar for all samples in an acid medium. We hypothesized that the sour starch with the best expansion property may contain an amylase that hydrolyzes the product during measurement, lowering the viscosity of the medium. Because this amylase should be active in neutral and basic pH, we tried to determine amylase activity within this sample by establishing the presence of reducing sugars and starch solubility. That is, if exo-amylase activity exists, reducing sugars should be released with time, but if endo-amylase activity exists, then starch solubility would increase with time.

In fact, we did not find change in either of these two parameters. This indicates that amylase activity is either very low or nonexistent.

We then investigated the macromolecular structure of starch, determining intrinsic viscosity by making the starch soluble with alkali (pH 13). Intrinsic viscosity represents the hydrodynamic volume of the molecules (polymers) and depends on two factors: first, the molecular weight of the polymer—the higher the molecular weight, the higher the intrinsic viscosity—and, second, the conformation of the molecules—the less “folded” they are in solution, the higher the intrinsic viscosity.

The intrinsic viscosity follows the same pattern as the maximum viscosity observed on the amylograph (Figure 9): it decreases within the first days of fermentation and within the first hours of sun-drying.

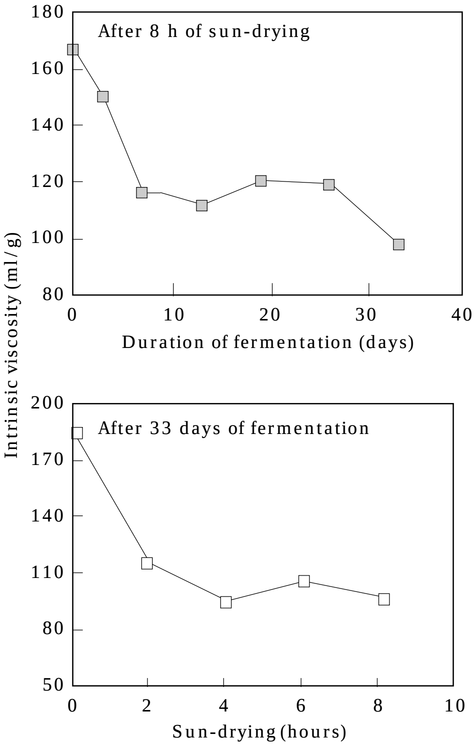

Figure 9. The intrinsic viscosity of two sets of samples of cassava sour starch.

A marked relationship therefore exists between intrinsic viscosity and the *pandebono*’s loaf volume: the lower the viscosity, the higher the loaf volume (Figure 10). We confirmed this relationship with another set of samples from a different cassava variety (CMC 40). How can the lowering of intrinsic viscosity be explained?

(1) A decrease of molecular weight—unlikely, because of the lack of amylase activity.
(2) A change in macromolecular conformation and increased convolution through interaction with other molecules. Such interaction facilitates polymer folding.

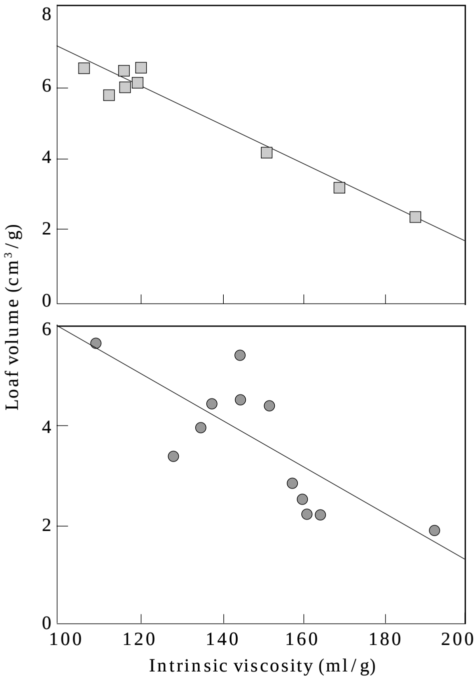

Figure 10. Relationship between intrinsic viscosity of sour starch from two cassava varieties and *pandebono* loaf volumes. (□ = variety ‘Amarga’; ● = variety ‘CMC 40’; *pandebono* = a traditional cheesebread eaten in Colombia.)

Conclusions

We did not see any differences in the crystalline structure of starch, but we showed that viscosity of solubilized (intrinsic viscosity) or dispersed (viscoamylograph) starch decreases with increased fermentation and sun-drying. Such reduction in viscosity seems related to the *pandebono*'s loaf volume, but is observed only at neutral and basic pH, and after 2 h of sun-drying but not after 33 days of fermentation. It is not linked to an amylase or acidic degradation of starch.

We can only propose some hypotheses to explain our results. The starch may have undergone an oxidative degradation (possible in oven-drying). Or interactions may have occurred with other molecules, either lactates or derivatives of lactic acid. Lactates cause starch to plasticize, and the effect is so notable that a patent has recently been taken out. Through lactates starch derivatives can be obtained. Volatile derivatives of lactic acid may contribute to gas production, and to the flavor and smell of sour starch. If flammable, their flame colors could indicate the quality of a sour starch.

CHAPTER 18

INFLUENCE OF GELATINIZATION CHARACTERISTICS OF CASSAVA STARCH AND FLOUR ON THE TEXTURAL PROPERTIES OF SOME FOOD PRODUCTS

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Abstract

Cassava flour contains fiber, sugars, and smaller quantities of lipids and other components. It exhibits properties different from those of cassava starch, which cooks to a more cohesive paste. The gelatinization characteristics of starch and flour, extracted from selected cassava cultivars, were examined. The peak viscosity of flour was generally lower than that of starch, although more stable. Swelling volumes were also correspondingly lower. The gelatinization temperature of flour, whether ascertained by differential scanning calorimetry or viscography, was consistently several degrees higher than that of starch. The lower peak viscosity and higher gelatinization temperature probably contribute significantly to the textural differences between flour and starch. Defatting and ethanol extraction had little influence on the gelatinization characteristics of either starch or flour, indicating that fiber, rather than lipids or sugars, probably makes the most important contribution to flour texture. The importance of these findings to the texture of food products made from cassava flour and starch is discussed.

Introduction

Cassava is an important root crop in many tropical countries, where the starchy and tuberous roots are eaten in various forms, including as starch and flour. The starch is extracted by a wet process and the flour obtained by milling dried chips.

The texture of cooked roots differs widely between cultivars, and considerable work has been carried out to identify reasons for this variability (Asaoka et al., 1992; Kawano et al., 1987; Moorthy et al., 1993a; Safo-Katanka and Owusu-Nipah, 1992; Wheatley et al., 1993). Few conclusions have been reached but the quantity and quality of the starch in the root and the presence of various nonstarchy polysaccharides are considered important.

Several differences also exist in the rheological and functional properties between starch and flour. We attempted to identify the reasons for these differences.

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Materials and Methods

Starch and flour were obtained from five cultivars of freshly harvested cassava roots (M-4, H-165, H-1687, S-856, and H-97), each having different cooking qualities. The main constituents of the samples—starch, fiber, lipids, and sugars—were determined by standard procedures. To assess the influence of lipids, samples were defatted by extraction (Soxhlet), using petroleum ether (40-60 °C). Ethanol extraction was similarly undertaken, with 80% ethanol (Soxhlet, 6 h), to examine the influence of sugars and ethanol-soluble components.

Differential scanning calorimetry (DSC) data were obtained by using Perkin Elmer DSC-2 equipment with Indium as a standard (temperature range 25-100 °C, at a heating rate of 10 °C/min). Gelatinization profiles of the samples (5%) were obtained on a Brabender Viscoamylograph (350 cmg [torque] sensitivity cartridge, heating rate 1.5 °C/min). Swelling volumes were determined at 95 °C (Schoch, 1964).

Results and Discussion

Table 1 presents the results of the chemical analyses of starch and flour from the five cassava varieties. Starch content on a dry weight basis was 98% or more in all the starch samples and between 79.1% and 86.0% in the flour samples. Crude fiber content was 0.13% or less in the starch samples, whereas it ranged from 1.50% to 2.98% in the flour. Earlier studies show similar starch and fiber compositions (Abraham et al., 1979).

The lipid content, by nature much lower than that of cereals, varied from 0.11% to 0.22% in the starches and from 0.25% to 0.56% in the flours. Lipids, in common with many surfactants, significantly affect starch by complexing strongly with amylose and amylopectin side chains, rendering these less labile (Krog, 1973). This capacity has been exploited for reducing the cohesiveness of potato starch products (Hoover and Hadziyev, 1981, 1982). Low levels of surfactants can have a profound effect on cassava starch (Moorthy, 1985). Ethanol-soluble constituents in the flours ranged from 2.5% to 3.7% and only 0.9% to 1.3% in the starch samples (data not shown). The predominant sugar in cassava flour has been identified as sucrose.

The recorded gelatinization temperatures (Table 2) reveal a consistent difference between the flour and starch samples. Comparing values for initial, maximum, and end temperatures, the results for flour are each 2-3 °C higher than for the corresponding starches. Components within the flour, by restricting access of water into the starch granules, can delay gelatinization. Surfactants and lipids, by forming complexes, are known to raise gelatinization temperatures (Osman, 1967). However, the defatted and ethanol-extracted flours had the same values as native flour, indicating that neither lipids nor sugars were responsible for enhanced gelatinization temperatures. Recent experiments on cassava starch show correlation between higher fiber content and higher gelatinization temperatures (Moorthy et al., 1993a). Thus, the elevation in gelatinization temperature of flour may be attributed to the fiber.

The DSC peak patterns of starch and flour from the same cultivar were similar. 'H-97' starch and flour had a characteristic shoulder in their peaks, whereas 'M-4' starch and flour had typically broad peaks. The peak

Table 1. Biochemical constituents of starch and flour made from five cassava varieties.

Variety	Product	Starch (%)	Sugar (%)	Lipids (%)	Crude fiber (%)
M-4	Starch	98.1	-	0.11	0.11
	Flour	86.0	2.20	0.45	1.50
H-165	Starch	98.0	-	0.22	0.13
	Flour	79.1	3.49	0.27	2.98
H-1687	Starch	98.2	-	0.18	0.15
	Flour	80.5	2.72	0.29	2.23
S-856	Starch	98.5	-	0.20	0.12
	Flour	81.2	3.23	0.56	2.56
H-97	Starch	98.3	-	0.20	0.11
	Flour	82.7	3.05	0.25	2.70

Table 2. Data from differential scanning calorimetry (DSC) of cassava starch and flour.

Variety	Product	Temperature (°C)			ΔH[a] (cal/g)
		Initial	Maximum	End	
M-4	Starch	68.10	73.24	78.54	2.95
	Flour	71.11	75.67	81.29	2.02
H-165	Starch	65.35	69.22	74.86	3.27
	Flour	68.65	72.02	77.19	2.14
H-1687	Starch	67.12	71.45	75.39	2.15
	Flour	70.02	73.90	79.11	2.22
S-856	Starch	65.62	70.14	74.94	2.65
	Flour	68.72	72.92	76.95	2.09
H-97	Starch	69.36	72.29	77.13	3.43
	Flour	71.82	75.02	79.92	2.27

a. ΔH = Enthalpy change.

patterns were not modified by defatting or by ethanol extraction, indicating dependence on the starch granular structure. The enthalpy of gelatinization of flour was lower than that for starch for every variety and neither defatting nor ethanol extraction affected the values to any noticeable extent. However, the lower enthalpy for the flour can be attributed in part to the lower starch content of the samples. The enhanced gelatinization temperatures in the DSC results for the flour samples are supported by the Brabender viscographic data (Table 3), which show that pasting temperatures for flours were 3-5 °C higher than for the respective starches.

The peak viscosity and viscosity breakdown for each flour were different from those of the corresponding starch, and most

Table 3. Viscosity and swelling properties of cassava starch and flour.

Variety	Product[a]	Viscosity (BU)[b]		Break-down	Pasting temp. (°C)	Swelling vol. (ml/g)
		V97	VH			
M-4	Starch	540	380	160	68-73	32.0
	Flour	380	320	60	71-74	28.0
	Starch (d.)	580	440	140	70-76	33.5
	Flour (d.)	380	310	70	72-75	29.5
	Starch (e.)	560	420	140	70-75	33.0
	Flour (e.)	410	380	30	72-76	29.0
H-165	Starch	940	480	460	66-78	38.5
	Flour	460	380	80	71-75	32.0
	Starch (d.)	1,000	580	420	69-82	39.5
	Flour (d.)	440	360	80	72-76	33.5
	Starch (e.)	1,000	520	480	69-83	39.5
	Flour (e.)	470	380	90	71-78	33.0
H-1687	Starch	540	480	60	70-81	33.5
	Flour	460	440	20	71-83	29.5
	Starch (d.)	570	510	60	71-82	33.5
	Flour (d.)	440	390	50	70-80	29.0
	Starch (e.)	520	480	40	70-83	34.0
	Flour (e.)	440	400	40	71-83	29.5
S-856	Starch	500	340	160	67-80	33.0
	Flour	440	360	80	71-86	29.0
	Starch (d.)	580	390	190	69-75	33.5
	Flour (d.)	470	380	90	70-85	29.5
	Starch (e.)	490	360	130	69-75	34.0
	Flour (e.)	740	390	80	70-89	30.0

a. (d.) = after defatting; (e.) = after ethanol extraction.
b. V97 = viscosity at 97 °C; VH = viscosity after holding at 97 °C.

pronounced in the comparatively much lower peak viscosity of flour from 'H-165'. Again, the lower starch content in the flour samples can account in part for the low readings. However, while the viscosity was lower, it was more consistent throughout the temperature program. Stabilization occurs through the presence of nonstarchy components in the flour. Lipids, although known to stabilize starch viscosity (Krog, 1973), had little effect here. The absence of stabilization in the ethanol-extracted samples indicates that sugars were not involved either. The reduced viscosity noted in all varieties was most pronounced in 'H-165', which had the highest crude fiber content. Stability may therefore result from the fiber affecting starch granule expansion and breakdown.

Defatting and ethanol extraction slightly enhanced paste viscosity in starch, whereas flour samples remained unaffected. In contrast, the slight increase in the flours' pasting temperature was probably due to the continuing presence of fiber in the defatted ethanol-extracted samples. Similar results have been obtained in a fiber-rich starchy flour extracted from fermented roots (Moorthy et al., 1993b). According to Osman (1967), high levels of sugars are needed to bring about perceptible changes in the viscosity of starch. The absence of significant changes in the peak viscosity of flours and starches thus indicates that sugars do not greatly influence viscosity in cassava.

Neither defatting nor ethanol extraction affected swelling volumes of the starches and flours, further indicating the influence of fiber in modifying starch rheological properties in the flour.

Cassava starch, cooked in water, generally gives a cohesive, long paste, whereas flour texture is less cohesive. Cohesiveness is attributed to the breakdown of starch molecules during heating and stirring. Early gelatinization can render starch more susceptible to breakdown because it undergoes a longer period of shear. High swelling necessitates the weakening of associative forces and thus easier breakdown of starch. The fiber may act as a barrier to earlier gelatinization and to higher swelling, reducing the cohesiveness of the paste.

Starch can act, for example, as a binder, thickener, or glazing agent in different foods (Smith, 1982[?]). In products where a cohesive texture is desired, such as gravies and puddings, starch would be favored, whereas in products where a nonsticky consistency is sought, flour would be more suitable. These mirror the findings of comparative studies conducted at the Central Tuber Crops Research Institute (CTCRI) for starch and flour in locally produced extruded products (when starch was used, the product tended to be hard and oily; with flour, the same product was crisp and nonsticky). Similarly, food items prepared from starchy flour made from fermented roots had a higher fiber content and better texture.

The study thus clearly indicates that fiber is a significant determinant of the characteristics and functional properties of cassava starches and flours. Future work should examine specific fiber components (e.g., cellulose and hemicellulose) and their interaction with starch. It should also focus on how rheological characteristics can lead to different functional properties in starch and flour.

Acknowledgments

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CHAPTER 19

TWO RAPID ASSAYS FOR CYANOGENS IN CASSAVA: THEIR EVALUATION, MODIFICATION, AND COMPARISON

*G. M. O'Brien** and *C. C. Wheatley***

Abstract

Two rapid, semiquantitative assays for total cyanogens in cassava were evaluated. These were the rapid picrate paper test, now well-known, and a recently proposed, rapid, paper test that involves the reagent tetra base (T.B.; 4,4'-methylenebis-[*N,N*-dimethylaniline]). A precise colorimetric assay was used as control. After preliminary evaluation, both assay methods underwent modification to improve accuracy of scoring. As a result, the reliability of the picrate assay was greatly improved. The T.B. assay was modified in the interests of safety. Evaluation of the latter assay over a range of temperatures from 20 to 35 °C showed no significant effects of temperature on performance when the new scoring system was used. The level of endogenous linamarase activity in each sample was an influential factor in rapid assay performance. In a series of comparative trials in three distinct ecosystems, the newly modified picrate assay produced correct results in 68% of cases compared with 66% by the T.B. assay. The T.B. assay, however, performed more reliably with low cyanogen samples, whereas the picrate assay was more reliable with intermediate cyanogen samples. The sampling protocol used at CIAT for the rapid assay of cyanogen contents of cassava clones was also evaluated.

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Introduction

Cassava (*Manihot esculenta* Crantz) is the fourth most important food crop of the tropics (Cock, 1985). An efficient source of low-cost carbohydrates, cassava is important for food security, particularly in Africa, and as an industrial raw material, especially in Asia and Latin America. Cyanogens have long been recognized as a toxic component of cassava's edible roots and leaves. The cyanogenic contents of the roots can vary from less than 10 to more than 500 mg/kg, measured as hydrogen cyanide (HCN), on a fresh weight basis (fwb).

Guignard first developed the alkaline picrate assay for cyanide in 1906. It was introduced in a semiquantitative, rapid format to CIAT and the International Institute of Tropical Agriculture (IITA), Nigeria, during the 1970s as a routine assay in cassava breeding programs. The rapid picrate assay is based on producing a red-brown color whose intensity increases with the quantity of HCN liberated from the sample. The HCN is liberated by autolysis and results from the hydrolytic action of the endogenous enzyme, linamarase, on cyanogenic glucosides in the sample. The picrate system, when used quantitatively, has been observed to produce very high results from cassava compared with other quantitative methods (Izomkun-Etiobhio and Ugochukwu, 1984; Mendoza et al., 1984). The assay has been criticized for falsely detecting cyanogens in acyanogenic samples (Nahrstedt, 1980). The rapid picrate assay originally used with a 9-point scale at CIAT has been criticized for giving poor correlation between cyanogen content and result (CIAT, 1993).

More recently, an alternative, rapid semiquantitative assay was developed, based on the reagent tetra base (T.B.; [4,4'-methylenebis-[*N*,*N*-dimethylaniline]). Also known as Michler's reagent, T.B. was originally used for qualitative assay of cyanogens (Feigl and Anger, 1966). The modified T.B. method was proposed as more sensitive and rapid than picrate (Bradbury and Egan, 1992). In this test, a blue-violet color forms, which increases in intensity and in violet hue the higher the sample's cyanogen content.

We have evaluated both the picrate and the T.B. rapid methods, using a reliable quantitative colorimetric assay (Cooke, 1978; O'Brien et al., 1991) as control. The assay method(s) selected after this evaluation would be expected to perform well in any cassava-growing environment. Because ambient temperatures in the tropics and subtropics vary considerably, we have carried out controlled evaluation and comparison of the two assay methods in three distinct tropical environments in Colombia under field conditions.

Reagents

Picric acid (99%), copper (II) acetate (99%), toluene (99.5%), sodium carbonate (99.5%, anhydrous) (E. Merck, Darmstadt, Germany), and T.B. (Sigma Chemical Company, St. Louis, USA) were used for the rapid methods. Reagents used for the colorimetric quantitative cyanogen assay were as described by O'Brien et al. (1991).

Alkaline picrate mixture was composed of picric acid (5 g) and sodium carbonate (25 g, anhydrous) dissolved in water and made up to 1 liter.

The T.B. mixture was as described by Bradbury and Egan (1992), a 1:1 (v/v) mixture produced on a daily basis, using two reagents:

(1) Copper (II) acetate, 3 g/L in 15% acetic acid.
(2) Tetra base, 3 g/L in acetone.

According to Bradbury and Egan (1992), the two reagent solutions should be stable for several months. But we noted a slight darkening of the reagent mixture made from reagents 3 weeks old and older. Reagents were therefore freshly made every 3 weeks.

Because of the highly toxic and carcinogenic nature of T.B., nitrile rubber gloves were used in handling. The T.B. reagent was prepared and stored in a fume-cupboard.

Reagents for assay of linamarase activity were as described by Cooke (1979).

The Tetra Base Assay

The T.B. rapid assay of Bradbury and Egan (1992) represented a new development in cassava cyanogen assay, which had been tested, using only low-cyanogen cultivars. The assay was also reported to be a little more rapid at higher ambient temperatures, suggesting that changes in temperature may affect the endogenous linamarase in a given sample (J. H. Bradbury, 1992, personal communication).

This reference to linamarase enzyme also prompted interest in the relationship between the amount of endogenous linamarase in a given sample, its activity under given environmental conditions, and, consequently, the reliability of autolytic assays. Thus, evaluating the T.B. assay in some detail became necessary. At CIAT, Palmira, the T.B. assay was run at different temperatures, with an assay of endogenous linamarase activity in parenchyma surrounding the sample taken for the T.B. assay. The quantitative, colorimetric assay of cyanogen content was used as control. The duration of the assay was determined after constantly observing samples under assay for 3 h and after an overnight period. The testing of the method resulted in a 1-h assay.

Conducting the assay

The T.B. assay was carried out in quadruplicate. A central disc was sliced out crosswise from a cassava root and parenchymal plugs removed (Figure 1). The plugs were trimmed with a scalpel to 0.5 cm thick, placed individually in small glass vials (2 x 5 cm), and sealed with tightly fitting, plastic stoppers. The plugs were maintained in the vials for 1 h before assay, to allow buildup of HCN in the vial. The assay was then carried out.

To start the assay, the stopper in the sample vial was replaced by a similar stopper with a T.B. test-paper attached, so that the paper was suspended inside the vial, 1 cm above the sample. The blue-violet color produced at the bottom end of the paper was recorded after 10 and 60 min. The result was interpreted in terms of cyanogen content.

The T.B. test-paper was made as follows: paper strips (Whatman's no. 1 filter paper, 4 x 1 cm) were attached to clean vial stoppers with adhesive tape. A 1-cm portion at one end of the paper was attached to the stopper, leaving a length of 3 cm to act as support for the T.B. mixture. The stoppers and papers were placed within the fume cupboard. One drop of T.B. mixture was placed on each paper at the end away from the stopper. The drops of mixture were left to soak through before each paper was sealed in an empty vial for safety, before assay.

To evaluate the T.B. assay method, assays were made of 72 cassava roots from 10 varieties, ranging between 10 and 456 mg/kg total cyanogens (as HCN, fwb). In each case, the root was first sampled for T.B. assay, then the rest of the peeled root was assayed for both total cyanogens and endogenous linamarase activity (Figure 1) by quantitative colorimetric assay (Cooke, 1978; O'Brien et al., 1991).

Tetra base assays were carried out at 20, 25, 30, and 35 °C, using an incubator. At least one root from each of the 10 cassava clones used in the experiment was assayed at each temperature. The samples were stored in the incubator during the 1-h preassay period and during the assay

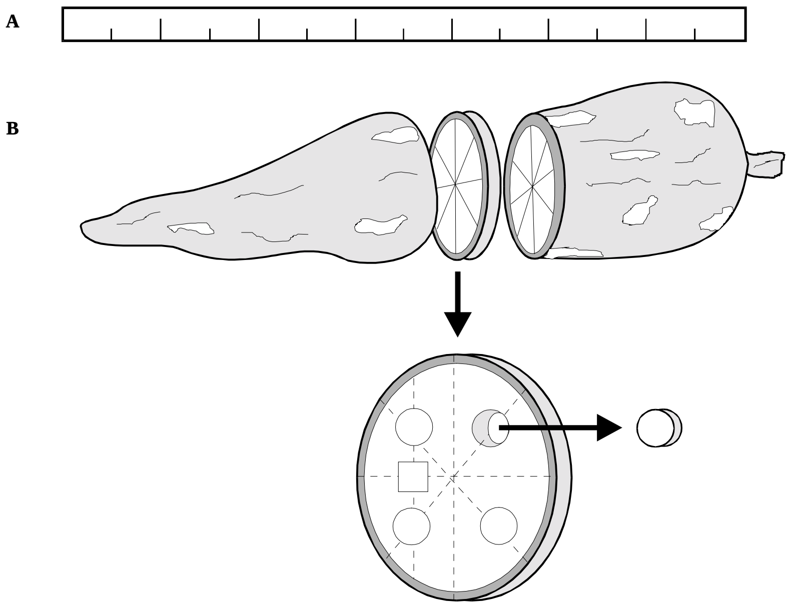

Figure 1. Steps in sampling a cassava root for rapid and quantitative cyanogen assays. (A) The root is first measured longitudinally and a disc, 1 cm thick, is removed from the center. (B; i) The geometric radius of the disc is measured from the center to the inner edge of the peel. (ii) Half way along a radius, a 1-cm round plug is removed with a borer. The plug is used for the tetra base assay. The sampling is replicated four times. (iii) From the space between two plugs, again half way along a radius, a 1-cm cube is cut out with a scalpel. The cube is used for the picrate assay. (iv) The rest of the root is peeled and the parenchyma chopped into cubes of about 1 cm^3. From these, a random sample of 50 g is quantitatively assayed for total cyanogens. Where required, another 50-g sample is taken for a linamarase enzyme assay.

itself. A 10-point numerical scale was devised, using the "Munsell color guide." It was based on the intensity of color attained, differing from that used by Bradbury and Egan (1992). The scale ran from very pale blue to deep violet.

Figure 2 shows the scores obtained by 72 roots in a 1-h test of their cyanogen contents. The relationship between total cyanogens and T.B. score in the 1-h test was linear only to about 50 mg/kg (as HCN, fwb). Most samples with cyanogen contents greater than 50 mg/kg produced a score between 8.5 and 10. Roots containing more than 100 mg/kg, almost without exception, gave scores between 8.5 and 10 within 10 min. Accordingly, a system of scoring (Table 1) for total cyanogens in cassava parenchyma was devised. The maximum permitted error in this grouping method was ± 1 mg/kg. A sample with a cyanogen content of 50.9 mg/kg could therefore be classed either in range 1 or range 2.

Table 1. Tetra base rapid assay, grouping format.

Range	Score	Total cyanogens (mg/kg as HCN, fwb)
1	<8.5	0-50
2	<8.5 after 10 min, >8.5 after 1 h	50-100
3	>8.5 after 10 min	>100

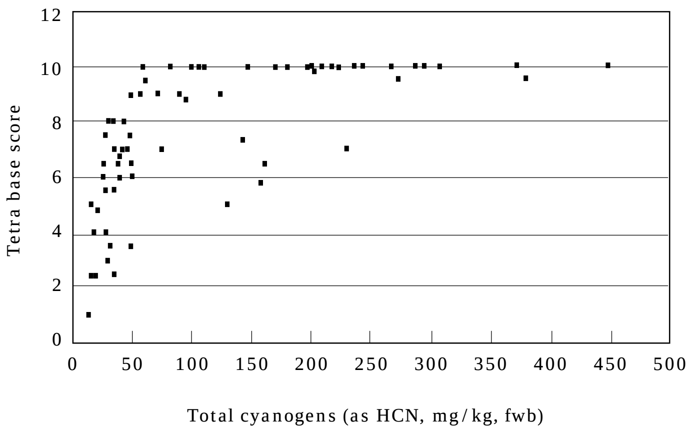

Figure 2. Evaluation of the tetra base assay used at CIAT, Palmira, to determine the cyanogen content of 72 roots from 10 cassava varieties.

Of the 72 assays carried out in this experiment, 61 results proved to be correct within the grouping format shown in Table 1. Thus, 84.7% of all results were correctly assayed.

Influence of endogenous linamarase activity

During the T.B. experimental work at CIAT, the endogenous linamarase activity of roots being assayed was measured colorimetrically. Activity ranged between 0.03 and 0.63 enzyme units per gram (EU/g, fwb). The T.B. score and colorimetric assay correlated better when data points from samples with less than 0.2 EU/g were removed, reducing the total from 72 to 43 cases. The Spearman correlation of linearity increased from 0.77 to 0.85. Hence, T.B. performance in roots with linamarase activity below 0.2 EU/g was negatively affected.

It is unsurprising that a sample's endogenous linamarase activity should affect results in a system where the parenchymal sample is neither grated nor macerated in buffer and where a significant degree of autolytic breakdown of cyanogens is sought within 1 h. Cooke and De la Cruz (1982) found that 24 h in excess buffer was needed for a complete autolytic breakdown of cyanogens in a cassava sample. Yet, 84.7% of all results in this experiment were correctly assayed, regardless of endogenous linamarase activity and of temperature within the range stated (20 to 35 °C).

This experiment and its results are described in greater detail elsewhere (O'Brien et al., 1993).

Picrate Assay

Plant breeding programs have been routinely using the alkaline picrate rapid assay for about 20 years, unlike the relatively untested T.B. assay. The original scoring format, used for the picrate assay, assigned a cyanogen-content range to each of the nine points on the color scale:

Score	Total cyanogens (mg/kg, as HCN, fwb)
1 = pale yellow	<10
2	10 - 15
3	15 - 25
4	25 - 40
5	40 - 60
6	60 - 85
7	85 - 115
8	115 - 150
9 = dark brown	>150

Some time before this project began, CIAT had made a limited evaluation of the picrate rapid assay. The original scoring format, with its 9-point scale, was regarded as unworkable because of errors (CIAT, 1993). The method of scoring was thus modified into anecdotal ranges:

Score	Cyanogen contents
1-4	Low
5-7	Medium
8-9	High

With the picrate assay, we evaluated only this “anecdotal” scoring system, assigning specific quantities to the anecdotal ranges listed above. The assay was compared with the evaluated and modified T.B. assay, under field conditions, using the quantitative colorimetric cyanogen assay as a control.

For the picrate assay, a cube was cut from the parenchymal disc taken from the root (Figure 1) and placed in a 12-cm test tube. Five drops of toluene were placed on to the sample. The tube was tightly sealed with a rubber stopper, entrapping a strip of paper (Whatman’s no. 1, 6 x 1 cm), saturated in alkaline picrate mixture and suspended above the sample. After 10 h (Pivijay) or 12 h (Palmira and Cajibío), the resultant color change was noted and interpreted in terms of cyanogen content.

Field-Based Comparison of the Two Rapid Methods, with Colorimetric Control

Three sites were selected for this work:

(1) Cajibío (near Popayán, southwestern Colombia): a highland area, 2,000 m above sea level, temperatures were 19 to 26 °C during trials.
(2) CIAT (Palmira, southwestern Colombia): mid-altitude, 1,000 m above sea level, temperatures were 26 to 33 °C during trials.
(3) Pivijay (North Coast, Colombia): at sea level, temperatures of 30 to 34 °C during trials.

In this experiment, 100 roots from 12 different clones were assayed. Each root was sampled for both the rapid T.B. assay and the rapid picrate assay (Figure 1). The rest of the root parenchyma then underwent quantitative colorimetric assay.

Table 2. Scoring ranges and levels of accuracy for tetra base and picrate rapid assays.

Group	Scoring ranges			Assay accuracy (%)		
	1	2	3	TB	Picrate	Q. color.
A	0-50	50-100	100+	66	68	100
B	0-40	40-90	90+	61	73	100
C	0-60	60-110	110+	68	65	100

Using the results of the 100 analyses carried out, three range groups of total cyanogen content (measured in mg/kg of HCN, fwb) were considered for scoring in each rapid assay and their levels of accuracy evaluated (Table 2). Group B gave 73% correct results for picrate but only 61% for T.B. Group C gave 65% for picrate and 68% for T.B. Group A gave the most favorable proportion of correct results for both the T.B. (66%) and picrate (68%) methods.

Of the three groups, group A was adopted. Hence, the picrate rapid assay gave slightly but not significantly better results than the T.B. rapid assay. Also, the picrate scoring format was slightly modified: the score 7 was reassigned to high instead of intermediate cyanogen content. The scores were therefore grouped as shown in Table 3. Figure 3 shows the results of comparing the two assays.

Table 3. Picrate rapid assay, revised group format.

Range	Score	Total cyanogens (mg/kg as HCN, fwb)
1	1-4	0-50
2	5-6	50-100
3	7-9	>100

A

Picrate assay score

	1	2	3
1	1	1	
2	7	8	13
3			10

Tetra base assay score

	1	2	3
1	9	3	4
2		2	3
3		2	17

B

Picrate assay score

	1	2	3
1			
2	1	12	3
3			14

Tetra base assay score

	1	2	3
1	1	1	
2		9	7
3		2	10

C

Picrate assay score

	1	2	3
1			
2	2	13	2
3		3	10

Tetra base assay score

	1	2	3
1	2	7	
2		7	3
3		2	9

Figure 3. Performance of picrate and tetra base assays in measuring total cyanogens in cassava grown in three ecosystems: A = CIAT, Palmira, mid-altitudes, southwestern Colombia; B = Cajibío, highlands, southwestern Colombia; C = Pivijay, sea level, North Coast, Colombia. Values indicated on the graphs' axes correspond to cyanogen content ranges (mg/kg, as HCN, fwb): 1 = 0-50; 2 = 50-100; 3 = ≥ 100. Correct results are reported in shaded boxes. Maximum error permitted is ± 1 mg/kg.

Sensitivity to cyanogen content

A statistical study was carried out on the data from this experiment, using a box plot model (SAS statistical analysis package). It was found that the methods produced different interquartile ranges (IQR, representing the central 50% of results) for cyanogen content. Range 1 denoted low cyanogen content and range 2 intermediate. The T.B. assay wrongly classified as "low" (range 1) a number of intermediate (range 2) and even some high (range 3) cyanogen samples. The picrate assay wrongly classified a number of high and some low cyanogen samples as "intermediate." For samples classified as "high" the IQRs were almost identical. Despite a small number of intermediate results wrongly classified as "high," nearly all samples with cyanogen contents of 100+ mg/kg or more were correctly placed within range 3 in both methods.

The findings of the three trials suggest that the picrate assay performs more reliably than the T.B. with roots containing 50-100 mg/kg as HCN, whereas the T.B. assay is more reliable than picrate with roots containing less than 50 mg/kg.

Comparing the two assays across ecosystems

Figure 3 shows that the picrate assay performed less well than the T.B. at CIAT, Palmira (almost 48% correct, compared with 70%, respectively, Figure 3A). But, at Cajibío, the picrate was better than the T.B. assay (87% compared with 67%, respectively, Figure 3B). At Pivijay, results were 77% for picrate compared with 60% for T.B. (Figure 3C).

This apparent irregularity probably had more to do with samples' cyanogen content than with other factors (temperatures were similar at CIAT and Pivijay). At CIAT, of the eight clones used, two produced roots whose cyanogen contents belonged to range 1. These roots were all erroneously classified under range 2 in the picrate assay, whereas the T.B. assay correctly classified them under range 1. In the other two trials, no low-cyanogen clone was used and the erroneous picrate results therefore did not recur.

Interpreting the results of the respective assays by means of the system chosen, no significant difference in overall performance was found between the two methods, with overall success rates of 68% (picrate) and 66% (T.B.).

That both methods produced results of which more than 30% were erroneous suggests that neither is particularly good for rapid screening. But variations in sample linamarase activity constitute an inbuilt source of error for any rapid autolytic assay of cyanogens in cassava. Nonautolytic methods (for example, destruction of the endogenous linamarase of the sample, followed by adding an excess quantity of exogenous linamarase) are more effective in this respect, but they are much slower for mass-screening samples. Autolysis is therefore still the only practicable system.

Evaluation of Field Sampling Method

In the comparison trials undertaken at Cajibío and Pivijay, the two rapid assays were compared, using the same root samples. The CIAT plant breeders' sampling method itself was also tested for its representativeness, using the quantitative colorimetric assay. CIAT usually samples clones for mass screening from a plot of 25 plants (5 x 5), selecting one plant near the center. From this plant, one root is selected for rapid assay of total cyanogens. The result obtained from this root is treated as representative of the entire plot.

At Cajibío, plots containing 25 plants of each clone, 13 months old, were used. At Pivijay, rows of six plants per clone, 8.5 months old, were used. In each case, one plant was harvested as representing its plot or row. From this plant, one root was chosen to represent the whole plant (and therefore the whole plot or row). At the same time, a further four roots were taken from the same plant: their parenchyma was pooled and triplicate extracts made. Their assay served as control to show whether the chosen root represented the whole plant.

A further four plants were harvested from the same plot or row. The parenchyma of their roots was thoroughly chopped and pooled. Triplicate assays were taken to show if the chosen *plant* properly represented the entire plot or row, and further, if the chosen *root* from that plant properly represented the entire plot or row.

The semiquantitative, rapid assays operate with three ranges of cyanogen content. To be representative, the sample root taken from a given plot or row had to give a result within the same range as the mean of the rest of the plot or row. Analysis of the data from the trial for representativeness shows that, in 47 cases out of 60 (i.e., in 78% of cases), the selected root was found to be representative both of the plant from which it was taken and of the group of five plants taken to represent the entire plot or row. Thus, the sampling method appears satisfactory, although it would be desirable to continue and expand this investigation, extending it to other cassava clones.

Conclusions

In comparing the Bradbury and Egan (1992) picrate assay with a newly modified T.B. assay, the success rates of both were very similar—68% for picrate and 66% for T.B.

The high toxicity and carcinogenic nature of the reagent tetra base requires a comprehensive and carefully controlled methodology. In terms of reagent costs, the T.B. assay is potentially less expensive than the picrate assay, although costs associated with safety precautions and equipment are considerably higher. In view of these findings, the following recommendations are made:

(1) The newly modified, picrate assay should be used for rapid screening of cassava cyanogens in all cases, except:

   (a) where a significantly high proportion of low-cyanogen clones (0-50 mg/kg, fwb) are used (i.e., where the risk of rejecting low-cyanogen material would be high); and
   (b) where a very rapid result is required.

(2) Under circumstances described in (1a) and (1b), the tetra base assay should be used but only if:

   (a) a well-maintained fume cupboard and good disposal facilities are available; and
   (b) workers have been trained and are willing to apply strict safety procedures.

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CHAPTER 20

ACUTE POISONING IN TANZANIA: THE ROLE OF INSUFFICIENTLY PROCESSED CASSAVA ROOTS

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Abstract

In 1988, an outbreak of acute poisoning occurred in a drought-stricken district in southern Tanzania. Studies carried out in the area revealed that the victims had high levels of thiocyanate, a cyanide metabolite found in the body's plasma and urine. The high dietary cyanide came from consuming insufficiently processed roots of cassava, the only crop to survive the prolonged drought. Because of food scarcity, the customary, but lengthy, sun-drying of peeled cassava roots was replaced by a repeated pounding and sun-drying of peeled roots to obtain flour for consumption the same day. An experiment in one village showed that the principal source of dietary cyanide comprised the high residual levels of cyanohydrin (the intermediate breakdown product), which ranged from 16 to 20 mg CN equivalent per kg dry weight. The shortened processing method adopted during the drought resulted in high glucoside levels ranging from 3 to 879 mg CN equivalent per kg dry weight in the final products. Rapid, but more effective, tissue disintegration and drying techniques that easily remove cyanogenic glucosides and cyanohydrins from the roots and prevent poisoning are urgently needed in this area. An intervention program has been established to develop an extension package for cassava processing, and to make the population aware of the problem and adopt more efficient processing methods.

Introduction

The advantages of cassava as a food security crop in sub-Saharan Africa usually outweigh the nutritional drawbacks that sometimes make cassava appear an inferior food. Drawbacks include low protein content of the roots, low energy density, and potential toxicity from the presence of the cyanogenic glucosides linamarin and lotaustralin (Rosling, 1987).

The amount of glucosides, mainly consisting of linamarin (90%), can reach 1,500 mg CN equivalent per kg dry weight in fresh roots, particularly in those of bitter varieties grown for their higher yields (Sunderesan et al., 1987). Environmental factors such as drought, pests, and diseases may increase the glucoside content (Gondwe, 1974). If the food security provided by cassava is to have an optimal impact on community health,

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then the nutritional drawbacks must be avoided or balanced. Supplementing cassava-based meals with various protein sources can balance low protein content and low energy density, and efficient processing can solve toxicity problems.

During processing, disintegrating the root tissue releases an endogenous enzyme—linamarase—which hydrolyzes the glucosides to the corresponding intermediate products: cyanohydrins (Figure 1). The intermediate products at pH >6 spontaneously decompose to volatile hydrogen cyanide (HCN), which rapidly evaporates into the air or dissolves in water (Figure 1) (Cooke, 1978).

The glucosides, cyanohydrins, and HCN are collectively known as cyanogens, and efficient processing can reduce them all to negligible levels. If insufficiently processed roots are consumed, cyanide exposure can occur from glucosides or cyanohydrins breaking down in the gut. The human body detoxifies cyanide by enzymatically converting it to the less toxic thiocyanate (or SCN), using sulfur as a substrate. Sulfur is obtained from sulfur-containing amino acids in the diet (Banea et al., 1992). The thiocyanate is found in serum and urine, through which it is excreted. Thus, cyanide exposure in humans can be estimated by determining thiocyanate in serum and urine.

Despite cassava being extensively used as food, reports of acute poisonings are rare. Most consumers are aware of the potential toxicity and know how to detoxify the roots. Where cases of acute poisoning and other effects have occurred, they were mainly in populations suffering severe food shortages (Rosling, 1987). Lack of scientific attention to such populations may also partly explain the scarcity of reporting.

A prolonged drought occurred in Masasi District, southern Tanzania, in 1987/88, causing a severe food shortage that motivated people to deviate from traditional cassava processing methods. The first visit to the District, in September 1988, was during a “situation of emergency,” declared by authorities who had received reports from many villages of acute poisoning after consumption of cassava-based meals.

Materials and Methods

The study area

In 1988, Masasi District, Mtwara region, southern Tanzania, had a population of 335,000, corresponding to 38 inhabitants per square km. Most of the soil in the District is a red loam, suitable for cassava and maize cultivation. The District has a unimodal rainfall that usually starts in late November and ends in May. Average annual rainfall is 940 mm and temperatures vary from as low as 18 °C

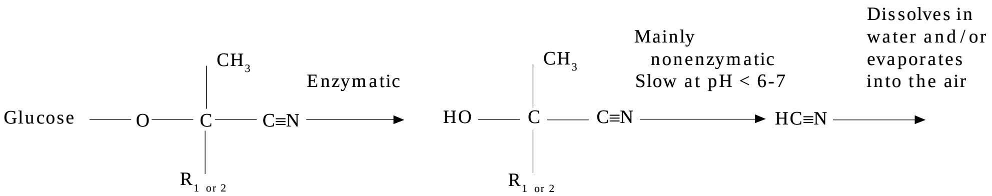

Figure 1. The breakdown of cyanogenic glucosides in cassava to produce hydrogen cyanide. $R_1 = CH_3$ for linamarin; $R_2 = C_2H_5$ for lotaustralin.

in July to as high as 35 °C in December.

Cassava is a secondary staple in Masasi but in difficult years becomes the primary one. In neighboring Newala District, cassava is the primary staple and people from Masasi often beg or barter cassava roots and seedlings from Newala during periods of food shortage. An earlier rapid rural appraisal revealed that prolonged sun-drying of peeled roots was the main cassava processing method in Masasi (Seenappa and Mlingi, 1988).

Table 1. Dietary practices during food shortages in 35 interviewed households, Masasi district, southern Tanzania, 1988.

Foods consumed in last 24 h	Households	
	(no.)	(%)
Cassava roots	35	100
Wild vegetables	30	86
Fruit (mainly mangoes)	29	83
Cassava leaves	19	54
Maize	10	29
Dried small fish	7	20
Legumes	6	17

Key informants, focus-group interviews, household surveys, and sample analysis

Local authorities and other key informants of Masasi District provided general information on the agricultural and dietary situation in the District before and during the drought in 1988. The district authorities selected, for the study, the villages of Mtandi, Chanikanguo, and Mumbaka, all 5 to 15 km from Masasi town and which had the highest numbers of reported cases of acute poisoning.

In each village, the leaders, elders, and women were gathered for focus-group interviews (Scrimshaw and Hurtado, 1987) on agricultural and dietary practices. One 10-cell unit (an administrative structure with about 10 households) was selected in each village. In the 35 households found in those units, the husband and/or wife were interviewed through a formulated open-ended questionnaire. This covered food consumption over 24 h (Table 1), cassava cultivation and processing, and occurrence of acute poisoning. To determine thiocyanate, an indicator of cyanide exposure, plasma and urine specimens were collected from 28 men, 37 women, and 30 children aged 5 to 14 years—a total of 95 subjects in the interviewed households.

A year later, Mtandi and Chanikanguo villages were revisited. Of the previously studied households, 12 volunteered to be briefly interviewed on diet and give urine specimens, that is, 32 subjects making up 9 men, 13 women, and 10 children. At the same time, specimens of cassava flour used in the interviewed households were collected. Clinical records of the Ndanda Mission Hospital and Masasi District Hospital were reviewed for cases of cassava poisoning. In Mumbaka, six households that had reported acute poisoning in 1988 were extensively reinterviewed on the symptoms experienced.

As a reference, thiocyanate was determined in plasma and urine specimens collected from 201 adults of both sexes, randomly selected, from a village in the Kilimanjaro region, northern Tanzania, where the dietary staple was banana, and cassava consumption was rare.

A cassava-processing experiment was conducted in Mtandi village during a follow-up study in 1988.

Cyanogen levels were determined in cassava flour obtained by two shortened processing methods used during the food shortage. Roots from 20 plants of a bitter variety, *chimaje*, were harvested from the same field. Roots were peeled and split lengthwise to form 19 identical pairs of batches. Under supervision, an elderly woman processed one set of batches into *chinyanya* flour and another set into small *makopa* (or dried root pieces), which were later pounded into flour, as practiced during the food shortage.

All specimens collected were kept frozen before analysis and thiocyanate was determined according to Lundquist et al., (1979, 1983). Cyanogens in flour samples were determined by an enzymic assay method modified by O'Brien et al. (1991), permitting separate quantification of glucosides, cyanohydrins, and HCN.

Results

Drought and food shortage

In normal years, cassava, maize, and sorghum dominate production in higher areas while rice is restricted to some lower swampy areas. Other food crops in the district include sweetpotatoes, cowpeas, and pigeon peas. Cashews, groundnuts, and *bambara* nuts are cultivated as cash crops. The area's rainfall pattern shows that rainfall was halved in the agricultural year 1987/88, the period before the food shortage. Interviews with key informants and focus groups confirmed that the drought from June 1987 to September 1988 caused the worst food shortages ever experienced in the district since 1966. Cassava was the only crop which survived; maize, rice, sorghum, and millet all failed.

The focus groups revealed that many families grow both sweet and bitter varieties of cassava but that, during the drought, roots from both varieties tasted more bitter than in normal years. Among the interviewed households, 71% cultivated only bitter varieties, while the rest cultivated both bitter and sweet. Of the six most commonly grown varieties, two, *chimaje* and *limbanga*, were identified as bitter; three—*liumbukwa*, *kigoma*, and *mba safi*—as sweet; and the sixth variety, *mreteta*, as either sweet (by 58% of households) or as both sweet and bitter (23%).

During the drought, the Prime Minister's Office (PMO) promptly reacted to news of the food shortage by distributing about 400 t/month of relief food, thus alleviating the threat of famine. But several households did not receive relief because it was insufficient, and used mainly to induce people to cultivate communal fields in the most affected villages. Old and disabled people received free relief food.

Cassava processing

In normal years, most cassava is processed by direct sun-drying for 1 to 4 weeks, depending on sunshine. The roots are first peeled and left whole if small or split if large. The resulting dried root pieces are known as *makopa*, and are either sold for cash or pounded into a flour used for making *ugali*, a stiff porridge. Legumes, small fish, cassava leaves (*kisamvu*), or other green vegetables constitute the relishes regularly eaten together with cassava or maize *ugali*.

During the food shortage, the normal processing method was replaced by two shortened methods. *Chinyanya* was faster and more widely used, according to the focus groups. Peeled roots were pounded into pieces, sun-dried for some hours, then repeatedly pounded and dried until a flour was obtained within half to

1 day. The second method, "small *makopa*," involved cutting fresh roots into finger-sized pieces and drying them on hot rocks until they could be pounded into flour. This method took 1 or 2 days, depending on the sunshine. The relish used to supplement the *ugali* made from such short-processed roots, was limited to *kisamvu* during the food shortage.

All households had consumed cassava during the 24 h before the interviews (Table 1). Although most households consisted of farming families (91%), during the food shortage, some relied on cassava either bartered or given free of charge. Of the 29% of households that had consumed maize, almost a quarter had mixed it with cassava flour to make *ugali*. All households admitted they had made some shortcuts in processing cassava by producing "small *makopa*" and 65% of households stated that they had used the *chinyanya* method.

Nevertheless, 9% of households fermented cassava by soaking the roots in water, and another 18% fermented peeled roots in covered heaps.

Acute poisoning and dietary cyanide exposure

Key informants stated that the acute poisoning following cassava-based meals frequently occurred in the Masasi villages between March and September 1988. All those interviewed agreed that they had seen or heard of villagers who were poisoned after eating cassava-based meals. Of the 35 households interviewed in the second round, 80% confirmed that most family members had suffered acute poisoning on one or more occasions. The pattern of symptoms, time of onset after meals, and duration of poisoning, as determined by the extensive interviews of households in Mumbaka village (Table 2) are consistent with information obtained from other interviews.

Clinical records for July 1988 showed that the Ndanda Mission Hospital treated several outpatients

Table 2. Results of interviews of six households regarding acute poisoning in Mumbaka village, Masasi district, southern Tanzania, 1989.

Poisoning parameters	Household code number[a]					
	1	2	3	4	5	6
Number of persons affected	6	5	6	6	4	3
Number of times poisoned in 1988	3	3	10	10	1	1
Interval between meal and onset of symptoms (h)	1	4	1	6	2	2
Estimated duration of poisoning (h)	4	8	24	8	10	8
Cassava was processed into:						
Chinyanya	y	y	y	y	y	y
"Small *makopa*"		y				
Symptoms of poisoning:						
Vomiting	y	y	y	y	y	y
Dizziness	y	y	y	y	y	y
Nausea	y	y	y	y	y	y
Palpitations		y	y	y	y	y
Weakness	y	y	y	y	y	
Diarrhoea		y	y	y	y	
Headaches	y		y	y	y	
Difficulties in seeing		y	y	y		

a. y = yes.

and admitted three patients for cassava poisoning. The first was a 7-year-old girl who suffered abdominal pain and vomiting after eating bitter cassava. She recovered the following morning without specific treatment.

Two days later, a 4-year-old girl was admitted semiconscious and dehydrated, but without fever. She had suffered a sudden onset of intense vomiting caused by eating pieces of cassava that were being dried. A routine neurological examination was normal. She received antibiotic treatment against suspected aspiration pneumonia and parenteral fluid, and recovered within 24 h.

Several days later, a 10-year-old boy was admitted unconscious after a sudden onset of poisoning symptoms from eating bitter cassava. Because antidotes were unavailable, he was treated with dextrose saline infusion and cortisone but died 3 h later.

In July 1988, the Masasi District Hospital also admitted three cases with similar symptoms and history. All recovered within 24 h.

Table 3 shows that, during the food shortage, the plasma SCN value was more than 10 times and the urinary SCN more than 100 times higher in Masasi subjects than in those from the Kilimanjaro village. When 32 subjects in Masasi were reexamined in the same month of 1989, a normal year, their mean urinary SCN was only 6% of the mean found the year before. All households still consumed cassava daily but this year the *ugali* was made from properly dried, normal-sized *makopa* (Essers et al., 1992).

Cassava processing experiment

The two shortened methods, *chinyanya* and "small *makopa*," were used to process the 19 pairs of batches of split, peeled roots from 20 cassava plants of the same bitter variety from the same field, as described on p. 169.

Each of the 19 batches processed to *chinyanya* flour was pounded and sun-dried four successive times and sieved after each pounding to obtain flour. Each of the 19 batches processed into "small *makopa*" was split into small finger-sized pieces that were sun-dried on hot rocks and then pounded into flour at the end of the day.

Table 4 compares the cyanogen content of flours obtained in the experiment by the two shortened methods with that of flour samples collected from 12 households in 1989, a normal year. Glucosides were very high in the "small *makopa*" flour and cyanohydrins were high in the *chinyanya* flour. The samples of "normal" flour had relatively high levels of glucosides but very low cyanohydrin content.

Table 3. Thiocyanate (SCN) levels[a] in subjects from Masasi, southern Tanzania, who eat cassava, and subjects from Kilimanjaro, northern Tanzania, who eat banana.

SCN sample	Cassava diet, drought year (n = 95)	Cassava diet, normal year (n = 32)	Banana diet, normal year (n = 201)
Plasma	335 ± 12		28 ± 4
Urine	1,120 ± 75	68 ± 9	7 ± 1

a. Values are given in µmol/L and as mean ± the standard error of mean.

Table 4. Cyanogen levels in cassava flour[a] processed by three different methods, southern Tanzania.

Contents	Processing experiment		Household flour made from normal-sized *mapoka*, normal year
	Chinyanya (n = 19)	"Small *mapoka*" (n = 19)	(n = 12)
Glucosides	90 ± 17 (12-296)	768 ± 107 (121-1,837)	120 ± 70 (93-879)
Cyanohydrins	48 ± 5 (16-120)	15 ± 4 (0-61)	7 ± 2 (0-17)
Hydrogen cyanide	6 ± 1 (2-12)	7 ± 0.5 (5-10)	6 ± 0.5 (4-9)
Total cyanogens	144 ± 18 (56-336)	971 ± 107 (131-1,855)	133 ± 71 (8-901)
pH	6.6 ± 0.1 (6.2-6.9)	6.9 ± 0.1 (6.6-7.2)	6.3 ± 0.2 (5.2-7.0)
Moisture (%)	13.5 ± 1 (6.0-23.6)	10.8 ± 0.2 (9.3-12.7)	10.6 ± 0.4 (9.5-14.4)

a. Values are given as mean ± standard error of mean. Values in parentheses are ranges. Cyanogen values are measured as mg of CN equivalent/kg of dry weight.

Discussion

Results confirm that most households of the Masasi District suffered severe food shortage during March to December 1988, and depended almost entirely on cassava—the only crop to survive the drought. All interviewed households daily consumed *ugali*, most of it prepared from cassava flour made from short-processed roots. All acute poisonings resulted from eating *ugali* prepared from such flour, especially *chinyanya* flour. Undoubtedly, thousands of people in the District were poisoned to some degree during the food shortage.

General symptoms of the case patients suggested cassava poisoning, which is characterized by an interval of 1 to 4 h from meal to onset and symptoms usually clearing within 24 h (Cheok, 1978; Essers et al., 1992). Cyanide, originating from cyanogenic glucosides occurring naturally in the roots, is presumed to cause acute cassava poisoning. But blood cyanide levels were never documented. We could not perform this complicated analysis during our study, and relied on thiocyanate. Levels of this easily determined cyanide metabolite in the affected population were among the highest ever reported in cassava eaters, suggesting strongly that cyanide caused the poisonings. The fact that the thiocyanate levels fell almost to normalcy the next year also supports the hypothesis of cyanide poisoning.

Cyanide

In contrast to earlier assumptions (Cheok, 1978), we concluded that cassava poisoning is not the result of ingesting HCN. The reason is that HCN evaporates at 28 °C, thus rapidly escaping during drying, as verified by the low levels found in all flour analyzed. Further losses occur when boiling *ugali*. Cyanide is also rapidly absorbed from the stomach, whereas the poisonings reported here occurred one to several hours after ingestion. The length of this interval suggests that the cyanide exposure resulted from ingested cyanide precursors, such as glucosides or cyanohydrins, that probably yielded cyanide in the small intestine.

Glucosides

Ingested glucosides are an unlikely source of cyanide exposure in the Masasi population. The reasons are, first, experiments with animals indicate that ingested linamarin can be absorbed unchanged and excreted intact in the urine (Barrett et al., 1977). Ingesting linamarin will only result in cyanide exposure if suitable microbial glucosidases are present in the gut, a mechanism still not confirmed as occurring in humans. Second, poisonings were associated mainly with consumption of *chinyanya* flour, which had relatively low glucoside levels. Third, the 1989 subjects had low urinary thiocyanate levels, despite the high levels of glucosides found in the flour collected from their households. An adult's estimated daily consumption of 0.5 kg of normal, household, cassava flour corresponds to ingesting 2,000 µmol of potential cyanide. The 68 µmol of thiocyanate per liter of urine constitutes only 3% of this amount, indicating that ingested glucosides do not result in cyanide exposure.

The rapid drying of "small *makopa*" in strong sunshine may result in high levels of glucosides, probably because the heat destroys the linamarase enzyme or reduces moisture content to a level that inactivates this enzyme before tissue disruption enables it to act on the glucosides. A daily consumption of 0.5 kg of "small *makopa*" corresponds to a potential cyanide yield of more than 300 mg, which is above the lethal dose (Hall and Rumack, 1986). Thus, the low mortality observed suggests that glucoside ingestion is of minor importance for cyanide exposure from insufficiently processed cassava.

Cyanohydrins

We believe that cyanide exposure results mainly from consumption of cyanohydrins in *ugali* prepared from *chinyanya* flour. Total cyanogens were higher in "small *makopa*" flour, but cyanohydrins were higher in *chinyanya* flour.

Very little is known about the fate of different forms of cyanogens during digestion in humans. In the alkaline environment of the small intestine, cyanohydrins should rapidly decompose to yield cyanide that is then absorbed. Our results support this hypothesis. The cyanohydrin level found in *chinyanya* can potentially yield about 1 mmol of cyanide at the estimated daily consumption of about 0.5 kg. This quantity of cyanide matches the high urinary thiocyanate level of 1 mmol/L found during the poisonings. The next, normal, year, when the *chinyanya* method was not used, the cyanohydrin levels in household flour were low, as were the urinary thiocyanate levels. Those who consumed cassava in the normal year or bananas had thiocyanate values below 100 µmol/L, corresponding to the levels of thiocyanate found in nonsmokers[1] in other countries (Lundquist et al., 1979).

Effects of cyanide exposure

Despite numerous cases of acute poisoning in many Masasi villages, very few deaths were reported and we could only document one. Hospital-based reports of cassava poisoning give an impression of high mortality (Cheok, 1978; Tylleskar et al., 1991), but anecdotal information suggests low mortality in several other outbreaks of cassava poisoning for which we could not find scientific

1. Cigarette smoke contains small quantities of cyanide.

documentation. Although many subjects reached blood cyanide levels at which symptoms of poisoning occurred, few reached levels that were two to four times higher than lethal (Hall and Rumack, 1986). The small number suggests that exposure to sudden high peaks of blood cyanide was rare. The rarity can be explained if the levels causing symptoms are partly reached by a cumulative effect from several meals, and partly caused by a decreased cyanide-to-thiocyanate conversion as the intake of sulfur amino acids (which provides the substrate for conversion) drops. A gradual cyanide release following meals would contribute to flat exposure peaks that usually reach levels causing only symptoms and, rarely, the higher levels causing death.

A different mechanism may also operate to reduce the mortality rate. The metabolism of linamarin and its effects has not been studied in humans. Some symptoms of acute cassava poisoning may be caused by non-lethal effects of absorbed, intact linamarin. If this hypothetical mechanism operates in parallel to cyanide exposure, it may explain why the frequency of diarrhoea seems higher than that reported for cyanide poisoning from other sources (Hall and Rumack, 1986).

The epidemic paralytical disease, konzo, characterized by abrupt onset of spastic paraparesis, has been attributed to high dietary cyanide exposure from insufficiently processed cassava. We screened the population in one village in Masasi for konzo and, as reported elsewhere (Tylleskar et al., 1991), found that the incidence of konzo was about 1 per 1,000 people during the period of high cyanide intake. The minimal dietary variation, provided by relief food, probably protected the population against a more extensive konzo epidemic. The highest incidences of this disease have been found in populations who exclusively consumed insufficiently processed cassava for several weeks to months (Howlett et al., 1992; Tylleskar et al., 1992).

In conclusion, the 1988 acute poisonings in Masasi resulted from consuming insufficiently processed cassava roots, and which therefore contained high residual amounts of cyanohydrins. Roots from bitter cassava varieties can be safely eaten after effective processing. Even in the shortened processing methods, cyanohydrin levels may easily be reduced by improving the disintegration and drying techniques used.

Toxic effects from cassava may occur in several areas of eastern Africa where bitter varieties have been introduced and where ineffective processing methods are used, especially during food shortages (Essers et al., 1992). However, cassava's agricultural potential may be used to improve food security with a positive effect on nutrition and health if attention is paid to its potential nutritional drawbacks.

An ongoing program aims to provide practical measures to prevent further outbreaks of acute poisonings during food shortages. This involves making the authorities and the population aware of the faults in the ineffective processing methods practiced in that area. The program will then develop an extension package for cassava processing that will use more efficient techniques, such as those for *gari* processing from West Africa. The extension package includes selecting the best and simplest message for the community, strategies to introduce new processing methods, and approaches to be used.

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CHAPTER 21

GARI, A TRADITIONAL CASSAVA SEMOLINA IN WEST AFRICA: ITS STABILITY AND SHELF LIFE AND THE ROLE OF WATER

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Abstract

Gari is a cassava semolina traditionally processed and widely consumed in West Africa. Its shelf-life is largely dependent on both its water content and storage temperature and relative humidity. This paper deals with *gari*'s adsorption properties in relation to water availability at 15, 25, and 30 °C. From the results, optimal packaging conditions can be estimated, thus providing an extended shelf-life for *gari*.

Introduction

Gari is a cassava semolina traditionally prepared and widely consumed in West Africa. *Gari* processing consists of pressing the juice out of peeled and grated cassava roots for 2 to 4 days, allowing a natural lactic fermentation to take place. The fermented mash is then cooked in an open clay vessel until the starch gelatinizes sufficiently (Chuzel, 1989; Zakhia, 1985). *Gari* is a "ready-to-use" food, generally consumed with milk (for breakfast) or added to hot sauces.

As demand for *gari* from urban markets is increasing, a better quality product with an extended shelf-life is needed. The shelf-life of packed and stored *gari* largely depends on storage temperature and relative humidity, and on the product itself (moisture content and water activity). These parameters determine the rate of *gari*'s microbial and physicochemical deterioration. The sorption isotherm, that is, the equilibrium between water activity and moisture content of a foodstuff, is a good indicator of the product's stability at different ambient temperatures and relative humidities (Bandyopadhyay et al., 1980).

Our study used adsorption isotherms to determine *gari*'s optimal shelf-life. Thus, we could propose a set of packaging recommendations to ensure better storage of *gari* in the tropics.

Materials and Methods

Samples of traditional Togolese *gari* (about 8% w.b. water content) were collected from a small factory near Lomé and packaged in sealed polyethylene bags. They were sent to Montpellier, France, and stored at

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Table 1. Experimental data for adsorption equilibrium of *gari* at 15, 25, and 35 °C (± SD) with salt sources and references.

Salt	15 °C		25 °C		35 °C	
	Equilibrium relative humidity	Moisture content (% d.b. ± SD)	Equilibrium relative humidity[a]	Moisture content (% d.b. ± SD)	Equilibrium relative humidity	Moisture content (% d.b. ± SD)
LiCl	0.119[b]	5.2 ± 0.4	0.110	4.8 ± 0.1	0.112[b]	4.4 ± 0.3
CH_3COOK	0.234[c]	7.4 ± 0.4	0.224	6.7 ± 0.3	0.230[d]	5.9 ± 0.2
$MgCl_2$	0.333[b]	8.1 ± 0.4	0.330	7.6 ± 0.2	0.320[b]	7.3 ± 0.3
K_2CO_3	0.431[c]	9.1 ± 0.2	0.428	8.6 ± 0.3	0.410[e]	8.6 ± 0.2
NaBr	0.607[c]	11.4 ± 0.7	0.577	11.0 ± 0.2	0.545[c]	10.3 ± 0.6
$SrCl_2$	0.741[b]	15.2 ± 0.8	0.708	14.3 ± 0.2	0.680[d]	13.7 ± 0.8
NaCl	0.755[c]	15.4 ± 0.5	0.753	16.1 ± 0.2	0.751[f]	16.6 ± 0.7
KCl	0.856[b]	20.7 ± 0.9	0.843	20.3 ± 0.6	0.829[c]	20.8 ± 1.2
$BaCl_2$	0.911[b]	24.5 ± 0.8	0.902	26.7 ± 0.6	0.894[g]	26.8 ± 1.2

a. Stokes and Robinson, 1949.
b. Acheson, 1965.
c. Greenspan, 1977.
d. Rockland, 1960.
e. Griffin, 1944.
f. Clarke and Glew, 1985.
g. Baxter and Cooper, 1924.

2 °C until evaluation. Adsorption isotherms were determined at 15, 25, and 35 °C, using the standard method recommended by the Water Activity Group (WAG) of the European Union (EU)[1] (Wolf et al., 1985). Equipment used comprised nine, sealed, glass jars, containing saturated salt solutions ranging from a_w 0.1 to 0.9 (Table 1). This a_w range is required practice for predicting the shelf-life of dried packaged products (Chirife et al., 1979).

In France, before measurements were taken, 3 g of *gari* samples were predried over phosphorus pentoxide (P_2O_5) for 10 days at about 20 °C (ambient temperature) to lower their water content to a minimum. They were then sprayed with a solution of sodium azide (0.5%) to inhibit the growth of microorganisms at high water activities ($a_w > 0.8$). They were placed in dishes resting on trivets standing in jars of salt solutions. The sealed jars were then submerged in an insulated water bath, the temperature of which was controlled to within ± 0.2 °C.

Equilibrium time was 21 days, as recommended by WAG's standard (i.e., 7 days for $a_w < 0.6$ and 14 days for $a_w > 0.6$), and in accord with the equilibration time required for cassava mash (Gevaudan et al., 1989). Equilibrated samples were oven-dried (103 °C, 24 h) in triplicate to determine moisture content.

The WAG uses the GAB (Guggenheim-Anderson-De Boer) model, which is believed to be the best for providing equations for describing food isotherms up to a_w 0.9 (Bizot, 1983; Van den Berg, 1985). The GAB equation is as follows (Labuza et al., 1985):

1. The Water Activity Group conducts the project "COST 90 bis" as part of the program for European Cooperation in the Field of Science and Technical Research, sponsored by the former European Economic Community, now the European Union.

$$\frac{a_w}{X} = \alpha a_w^2 + \beta a_w + \gamma \quad (1)$$

where:

$$\alpha = \frac{K}{X_m}\left(\frac{1}{C} - 1\right)$$

$$\beta = \frac{1}{X_m}\left(1 - \frac{2}{C}\right)$$

$$\gamma = \frac{1}{X_m . K . C}$$

X = water content (% d.b.)

X_m = percentage of water content corresponding to the occupation of all primary adsorption sites by one water molecule. "X_m" is also called the "monolayer."

C = the Guggenheim constant. $C = CN \exp [(H_1 - H_m)/RT]$

K = a correction factor for the multilayer molecules. $K = KN \exp [(H_1 - H_q)/RT]$

H_1 = the heat of condensation of pure water vapor

H_q = the total heat of sorption of the multilayer water molecules

H_m = the total heat of sorption of the monolayer

The GAB model's coefficients α, β, and γ were determined for each temperature by using a nonlinear, least-square regression as recommended by Schär and Rüegg (1985). The values of GAB constants X_m, C, and K were also calculated. The confidence of fit was judged by the relative root mean square error (% RMS).

Results and Discussion

Adsorption isotherms

Table 1 and Figure 1 show the average values and standard deviations of the equilibrium moisture contents for the water activities studied at 15, 25, and 35 °C, and their fitted GAB isotherms.

At low water activities ($a_w < 0.6$), the experimental curves agree with the sorption theory, that is, at constant a_w, an increase of temperature causes a small decrease of moisture content. At high water activities (0.7-0.9), moisture content increases with rise in temperature. The three calculated isotherms intersect at the following points:

isotherms 15 °C and 25 °C
where X = 13.0% and a_w = 0.66
isotherms 15 °C and 35 °C
where X = 11.5% and a_w = 0.59
isotherms 25 °C and 35 °C
where X = 9.5% and a_w = 0.48

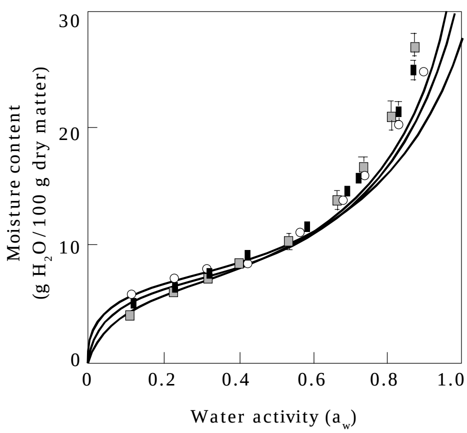

Figure 1. Adsorption isotherms of *gari* at three temperatures. Experimental points are means of triplicates. -○- = 15 °C; -■- = 25 °C; -□- = 35 °C.

The crossing of isotherms at high water activities with increasing temperature has already been observed in some foods and may result from the product's chemical composition and its treatments (e.g., heating, drying, and pregelatinization). Other foods showing this phenomenon are sucrose and fructose (Loncin et al., 1968), potato slices (Mazza, 1982), carrots (Mazza, 1983), Jerusalem artichoke (Mazza, 1984), and sultanas (Saravacos et al., 1986). The explanation is that some sugars increase their solubility with temperature, thus binding more water at higher temperatures and increasing the equilibrium moisture content.

The technological treatments involved in *gari* production (grating, fermentation, and squeezing) induce damage to about 3% to 6% of the cassava starch (Zakhia, 1985). During roasting, the starch is heated in the presence of water, but the initial moisture content of about 1 g g^{-1} (d.b.) of cassava mash does not allow the starch to completely gelatinize (Chuzel, 1989; Gevaudan et al., 1989). But crystallinity is lost and extensive swelling of the starch granules occurs. A complex metastable network forms, consisting of amorphous regions (containing plasticizing water) and hydrated microcrystalline regions that had not dissolved during the partial gelatinization and which serve as junction zones (Levine and Slade, 1988). All these factors strongly affect the polymer-water interactions (Radosta et al., 1989).

The sorption mechanism for starch is almost entirely governed by active sites, that is, the glucose residues of the starch polymer (Hill and Rizvi, 1982). We suggest, therefore, that increases in both temperature (to 35 °C) and water content (for a_w between 0.5 and 0.7) initiate a "collapse" that makes the soluble starch (amorphous fractions and branched segments) leach out. This increases the number of available adsorption sites (glucose residues) and explains why *gari* becomes more hygroscopic at higher temperatures and water activity. Moreover, the degree of starch damage in gelatinized starchy products is measured by the solubility and swelling indices at 30 °C, which depend on the ability of starch to absorb water (Anderson et al., 1969).

Slade and Levine (1988) and Orford et al. (1989) have also discussed the physicochemical effect of water, acting as a plasticizer of the amorphous regions in the starch native granule, on the temperature of the vitreous transition that occurs during native starch gelatinization. Only the water included in the starch granule (about 10% w.b.) is involved in this process; the vitreous transition temperature decreases sharply with increasing water content. This plasticizing effect could also explain the observed adsorption behavior of *gari*. The amorphous matrix of *gari*, which is partially plasticized at room temperature by excess water (> 12% d.b.), would become more plastic if the temperature increased to 35 °C. The mobility of chains is then enhanced and the free volumes inside the polymer increase. As these free volumes may absorb more water, the sorption sites are then more available.

Gari *storage*

In tropical countries, high relative humidity and temperature make long-term storage very difficult. So predicting the shelf-life of packaged *gari* in terms of its storage conditions and quality becomes important. The Heiss and Eichner (1971a; 1971b) model allows calculation of the potential storage time based on a critical a_w for a particular system under given storage conditions. This model equation is:

$$\Theta_c = \frac{\ln((X_e - X_i) / (X_e - X_c))}{K_x (A / W_s)(P_o / S)} \qquad (2)$$

where:

Θ_c = Potential shelf-life of the product (time in days for the packaged product to suffer microbial and biochemical deterioration with loss of sensory quality).

X_e = Equilibrium moisture content (g g^{-1}, d.b.) of the product (if it is left in contact with the atmosphere outside the package). "X_e" depends on temperature, relative humidity and on the product adsorption isotherm.

X_c = Safe storage moisture content of the product (g g^{-1}, d.b.), that is, the moisture content corresponding to the safe storage borderline a_w. "X_c" is calculated for the borderline a_w by successive iterations from the GAB regression equation until the difference between two calculated "X_c" is lower than 0.01.

X_i = Initial moisture content of the product when it is packaged (g g^{-1}, d.b.).

K_x = Permeability of the package to moisture vapor (kg $H_2O.m^{-2}.Pa^{-1}.day^{-1}$).

P_o = Vapor pressure at storage temperature (in Pa).

A = Surface area of the package (m^2).

W_s = Weight of the product (kg of dry matter in the package).

S = Slope of the product isotherm (assumed linear over the range between "X_e" and "X_c").

Using the Heiss and Eichner model, we estimated the shelf-life of *gari* packaged in 1-kg polyethylene bags (A = 0.124 m^2, K_x = 2.28 10^{-6} kg $H_2O.m^{-2}.Pa^{-1}.day^{-1}$) at three temperatures (15, 25, and 35 °C) and four initial moisture contents (6%, 8%, 10%, and 12% d.b.) (Table 2). As ambient storage conditions, we considered a relative humidity of 0.9 (which is the safe storage borderline humidity) and an a_w of 0.7 (which is the safe storage borderline a_w generally used for most products) (Pixton, 1982). Adeniji (1976) observed a significant growth of mould in *gari* stored at 27 °C, in a relative humidity of 0.7 and having an equilibrium content of 14.5% (d.b.). For a_w 0.7, our sorption curves at 15, 25, and 35 °C give 14.0%, 14.2%, and 15.3% (d.b.) as equilibrium moisture contents (Table 2). These values agree with those of Adeniji (1976). Moisture contents around 14% (d.b.) allow *gari* to maintain a crispness that consumers greatly appreciate (Chuzel, 1989; Ekundayo, 1984).

Moisture contents before packaging (X_i) are those generally found in local *gari* sold in tropical markets. lkediobi and Onyike (1982) mention moisture contents ranging from 4% to 19% (d.b.). The crossing-over of adsorption isotherms described above leads to the following paradox: *gari* stored at 35 °C seems to be better than that stored at 25 °C for a moisture content of 12% (d.b.). This moisture content is usually obtained with traditional *gari* processing (Chuzel, 1989), although storage time was less than 1 month under the given conditions.

Table 2. Estimated shelf-life (days) for safe storage of *gari* at a_w 0.7 at four initial moisture contents (d.b) and three storage temperatures.

Initial moisture content (d.b.)	Equilibration temperature (°C)[a]		
	15 (14.0)	25 (14.2)	35 (15.3)
6	181	90	57
8	166	85	52
10	140	73	45
12	89	24	30

a. Values in parentheses are equilibrium moisture contents (d.b.) for a_w 0.7 (from experimental adsorption isotherms).

We also focused on the permeability of packaging materials. Polyethylene, especially the high-density type, tends to inhibit water vapor transfer, but is permeable to oxygen and carbon dioxide, which may oxidize *gari* or cause loss of its aromas. Polypropylene is less permeable to water vapor and oxygen, but, because it is more expensive than polyethylene, it is less suitable for storing *gari* as a daily foodstuff for low-income consumers.

Conclusions

Gari processing modifies the structure of native cassava starch so that, at high water activity, it becomes more hygroscopic as temperature increases. Our study pointed out a “collapse” (not yet observed in other starchy products), caused by the partial gelatinization of *gari* starch. The GAB regression equation was adequate for fitting sorption isotherms of *gari*.

The shelf-life of *gari* was theoretically estimated for three storage temperatures (15, 25, and 35 °C) at a relative humidity of 0.9 (which is usual in the tropics). For a low-cost storage of at least 3 months at about 30 °C, we recommend packaging *gari* at an initial moisture content of about 8% (d.b.) in polyethylene bags. The bags should be sealed and tightly packed in cardboard boxes for both physical convenience and to prevent oxidation and reaction to light.

Further research should be carried out to determine the safe storage water activity in the tropics, taking into account the initial microbial flora of cassava roots and the local quality requirements for *gari* quality, that is, color, crispness, flavor, and food customs.

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Session 4:

Bioconversion and Byproduct Use

CHAPTER 22

FERMENTATION IN CASSAVA BIOCONVERSION[1]

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Introduction

Cassava fermentation is traditionally practiced in the tropics. But both technology and product characteristics differ according to region and sociocultural conditions: *gari* in East and West Africa, *chikwangue* or *fufu* in Central Africa, and sour starch in Latin America. But they have in common the aim to eliminate the poisonous cyanide components and conserve cassava by lactic acidification.

The essential role of lactic acid bacteria in the three products was demonstrated by studies carried out by the Institut français de recherche scientifique pour le développement en coopération (ORSTOM) through the STD2 Program of the European Union (EU), otherwise known as "Improving the Quality of Traditional Foods Processed from Fermented Cassava" (Raimbault, 1992; Saucedo et al., 1990).

When producing *gari*, lactic acidification of cassava is rapid and detoxification is sometimes incomplete. Controlling through inoculation would improve quality. For *fufu* or *chikwangue*, retting is essential for texturing and detoxifying the cassava. Lactic acid fermentation is heterolactic, operating in association with secondary alcoholic and anaerobic fermentation to produce alcohol and organic acids such as butyrate, acetate, and propionate that develop special aromatic and organoleptic characteristics. As for *gari*, fermentation for sour starch (especially in Colombia and Brazil) is homolactic, but takes 3 or 4 weeks. Amylolytic lactic acid bacteria have been isolated from *chikwangue* by ORSTOM scientists and from sour starch by CIRAD scientists.

A. Brauman isolated a new strain, *Lactobacillus plantarum* A6, which was described by Giraud et al. (1991). Its physiological and enzymological characteristics for cultivation on cassava starch media, amylase production, and biochemical

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1. No abstract was provided by the authors.

properties have now been described (Giraud et al., 1992; 1993a; 1993b).

ORSTOM scientists have been researching solid fermentation cultivation of fungi on cassava and amylaceous components for more than 10 years. Soccol et al. (1994) showed that protein enrichment is possible by cultivating various strains of *Rhizopus*, even on crude, nongelatinized cassava flours. Saucedo et al. (1992a; 1992b; 1992c) studied, at the ORSTOM Laboratory, Montpellier, the growth and alcohol fermentation of cassava starch in solid-state fermentation, using a highly promising amylolytic yeast.

Swedish and African researchers have described the beneficial effects of lactic acid fermentation on the prophylactic and keeping characteristics of those traditional foodstuffs made from fermented cassava, maize, and mixed cereals, and of baby foods. These foods tend to increase children's resistance to diarrhoea.

All these studies are being continued in new projects comprising the EU-STD3 Program. Other EU studies are being conducted on cassava quality, environment, physical processing, and transformation at a low industrial scale to take advantage of the economic and commercial opportunities in Latin America.

Solid-State Fermentation of Cassava and Starchy Products

For more than 15 years, an ORSTOM group has worked on a solid-state fermentation process for improving the protein content of cassava, potatoes, bananas, and other starchy commodities used for animal feed. Fungi, especially from the *Aspergillus* group, are used to transform starch and mineral salts into fungal proteins (Oriol et al., 1988a; 1988b; Raimbault and Alazard, 1980; Raimbault and Viniegra, 1991; Raimbault et al., 1985). Table 1 shows the overall changes in composition between the initial substrate and final products. Through such techniques a cassava-fermented product with an 18%-20% protein content (dry matter basis) was obtained.

More recently, Soccol et al. (1993a; 1993b), also at the ORSTOM Laboratory, obtained good results with the *Rhizopus* fungi, of special interest in traditionally fermented foods. In particular, they studied the effect of cooking before fermentation on the availability of starch, protein content, and the rate of starch's bioconversion into protein (Table 2). They found that a selected strain of *Rhizopus oryzae* could transform uncooked cassava, which contains only 1.68% protein, into a fermented cassava containing 10.89% protein.

Table 1. Effects of *Aspergillus niger* on protein and sugar contents of different starches (percentage of dry matter) after 30 h of fermentation in solid-state culture.

Substrate	Initial composition		Final composition	
	Proteins	Sugar	Proteins	Sugar
Cassava	2.5	90	18	30
Banana	6.4	80	20	25
Banana waste	6.5	72	17	33
Potato	5.1	90	20	35
Potato waste	5.1	65	18	28

Table 2. Growth of *Rhizopus oryzae* in solid-state cultivation on cassava granules after various cooking treatments.

Treatment[a]	Dry matter[b]		Total sugar[c]		Proteins[c]	
	Initial	Final	Initial	Final	Initial	Final
I	60.90	46.48	80.01	46.78	1.20	11.69
II	59.18	45.35	84.11	60.72	1.61	12.40
III	57.95	42.12	82.44	52.57	1.56	13.93
IV	55.63	43.88	82.49	56.62	1.47	11.89
V	45.57	37.88	82.04	56.62	1.68	10.89

a. Treatment:

I = Cassava autoclaved for 30 min at 120 °C, frozen, dried, and ground

II = Cassava flour (40% water) autoclaved for 30 min at 120 °C

III = Cassava flour (30% water) autoclaved for 30 min at 120 °C

IV = Cassava flour (30% water) vapor cooked for 30 min at 100 °C

V = Untreated crude cassava flour

b. g/100 g total weight.

c. g/100 g dry matter.

SOURCE: Soccol et al., 1994.

Table 3 shows results of amylase biosynthesis in solid or liquid culture, using raw or cooked cassava. The amount of glucoamylase was 10 to 15 times higher in solid than in liquid culture, and higher in raw starch medium than in cooked cassava.

This work is being continued in the EU-STD3 Program at the Bioconversion Laboratory of the Universidad del Valle, Cali, Colombia. It focuses on simplifying cassava processing by learning more about the specificity of *Rhizopus* strains in degrading the raw starch granule. But clean flours of raw cassava are needed. The common flours of cassava contain too much natural microflora to allow microbial studies with fungi; they must first be sterilized and (unfortunately) gelatinized. Ramírez et al. (1994) developed raw cassava flour with a very low content of bacteria and fungi, and little gelatinization.

To measure gelatinization, the simple method of Wotton et al. (1971) was adopted and a good correlation coefficient for the calibration curve was obtained. Table 4 shows the effect of thermic treatment and microwaves on starch gelatinization in cassava flour (water content typically lower than 10%). Where water content was very low, gelatinization was also low.

The same thermic treatment of dry cassava flour eliminated the natural microflora contained in raw flour, from 10^9 bacteria/g of dry flour to fewer than 10^3 bacteria/g after heating the flour for 30 min at 90 °C. With gelatinization limited to less than 5% under such conditions, obtaining clean, raw cassava flour is possible in the laboratory.

Figures 1 and 2 show the effects of various physical and thermic treatments on the bacteria content of cassava flour. Cassava flour will be used as a solid substrate for cultivating *Rhizopus* strains, and to compare the capacity of selected strains to grow on raw or gelatinized cassava starch.

Table 3. Effect of cooking and type of culture on the growth and amylases of various strains of *Rhizopus oryzae* cultivated on cassava granules.

Strain of *Rhizopus*	Liquid-state culture[a]						Solid-state culture[a]					
	Raw cassava			Cooked cassava			Raw cassava			Cooked cassava		
	α–amylase (U/g DM)	Gluco-amylase (U/g DM)	Protein (g/100 g DM)	α–amylase (U/g DM)	Gluco-amylase (U/g DM)	Protein (g/100 g DM)	α–amylase (U/g DM)	Gluco-amylase (U/g DM)	Protein (g/100 g DM)	α–amylase (U/g DM)	Gluco-amylase (U/g DM)	Protein (g/100 g DM)
28168	42.20	9.60	3.90	157.20	3.10	10.00	39.30	55.30	10.60	178.40	46.22	12.30
34612	40.40	7.30	4.60	168.50	5.70	9.30	55.00	70.00	12.60	170.00	47.00	14.10
28627	76.00	7.80	4.00	145.40	3.30	9.60	98.00	108.00	11.40	167.00	37.00	13.80

a. DM = dry matter; U = enzyme units.

SOURCE: Soccol et al., 1994.

Table 4. Effect of temperature and microwaves on starch gelatinization of cassava flour.

Temperature	Time (min)	Gelatinization rate (%)[a]			
		Exp. 1	Exp. 2	Exp. 3	Mean
Test 1 (80% gel.)		75.439	84.063	88.911	82.80
Test 2 (20% gel.)		25.411	26.184	29.702	27.10
80 °C	60	3.529	3.444	2.714	3.23
85 °C	30	3.529	3.357	3.487	3.46
85 °C		3.444	3.486	3.444	3.46
90 °C	30	3.572	3.444	3.572	3.53
90 °C	60	9.454	9.064	9.107	9.21
95 °C	30	6.961	5.546	5.803	6.10
100 °C	30	4.965	4.602	4.001	4.52
105 °C	30	6.961	5.503	5.301	5.92
120 °C	30	4.816	4.730	4.473	4.67
140 °C	30	4.773	3.100	3.100	3.66
160 °C	30	3.529	3.487	4.301	3.77
Autoclaving (121 °C)	15	3.572	3.100	4.301	3.66
Microwaves (Pot. 70)	5	2.886	2.410	2.842	2.71
Microwaves (Pot. 100)	5	2.971	2.242	2.242	2.49
Microwaves (Pot. 30)	15	3.879	3.057	3.915	3.62

a. Exp. = Experiment. Mean is across the experiments.

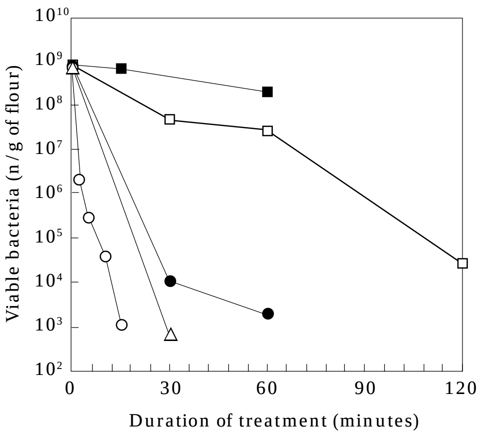

Figure 1. Total microflora (plate count analysis) in cassava flour, according to treatment. (■ = ultra-violet radiation; ○ = microwaves; □ = 80 °C; ● = 85 °C; △ = 90 °C.)

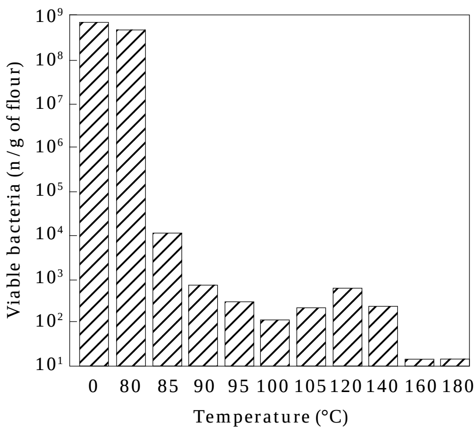

Figure 2. Effect of temperature on bacterial population in cassava flour.

Lactic Acid Fermentation of Cassava

Lactic acid fermentation is important for many traditional fermented foods, silage, and animal feed, and for recycling agroindustrial byproducts. Because of its acid, bacteriostatic, and bactericidal properties, fermentation prevents microorganisms, whether parasitic, saprophytic, or pathogenic, from breaking down vegetable material.

In tropical countries, lactic fermentation not only plays an important role in the traditional transformation of starchy foods, such as cassava, but also in the transformation and conservation of other foods, and fish and its byproducts. Two types of lactic fermentation exist:

(1) Homolactic, when more than 80% of total acidity and metabolites formed consists of lactic acid, and
(2) Heterolactic, when the percentage of acetic acid, propionic acid, and ethanol is more significant, and lactic acid represents 50%-80% of total acidity.

Lactic bacteria produce two types of lactic acid: L(+) and D(-). Only the L(+) form is assimilated by humans.

Previous studies, realized during the EU-STD2 Program in 1988-1991 (Raimbault, 1992), consisted of improving traditional fermented food made from cassava in Africa and Latin America. Three kinds of traditional foods were considered: *gari*, *chikwangue*, and sour starch. We demonstrated the essential role of lactic acid bacteria in all traditional processes.

Amylolytic lactic bacteria were isolated from fermented cassava. The first strain of *Lactobacillus plantarum* to be described as having very high amylolytic capacity was obtained from fermented cassava by A. Brauman in the Congo. Detailed physiological and biochemical characterization of this new strain is expected to be published soon by E. Giraud.

Mbugua and Njenga (1991) and Svanberg (1991a; 1991b), working in Tanzania and at the Uppsala University, respectively, have reported on the effect of lactic acid fermentation on the pathogen microflora content of traditional African foods.

Some of their results are reported in Table 5 and Figure 3, which show how lactic acid bacteria reduce the number of food-poisoning pathogens such as species of *Staphylococcus*, *Salmonella*, and *Shigella*, and *Escherichia coli*. High levels of such pathogens are sometimes found in traditional foods after processing under unhygienic conditions, especially those for malting maize during the rainy season in parts of tropical Africa.

Lactic fermentation of traditional foods reduces pathogenic bacteria from 10^8 to 10^3. The same authors also found a significant correlation between the resistance of young children to diarrhoea and eating acidified gruels.

We are bioconverting, through probiotics and bactericides, cassava flour and starch containing amylolytic lactic acid bacteria to isolate new strains from traditional foods. At the same time, we are broadening knowledge on the cultivation of lactic acid bacteria in starchy substrates. We hope such information will help elaborate new food and feed products.

Table 5. Effect of lactic acid fermentation on the content of pathogenic bacteria in traditional fermented foods in Africa.

Time (h)	Log number of bacteria/g food			
	Control	Nonfermented, acidified food	Fermented food	
			Flour (nonviable)	Gruel (viable)
Shigella flexneri				
0	6.8	6.7	6.4	6.0
3	6.6	5.8	5.1	4.0
7	7.0	4.2	5.5	3.3
24	7.0	4.1	3.7	2.7
Salmonella typhimurium				
0	8.5	8.1	8.3	7.7
3	8.0	6.7	6.0	7.1
7	7.9	5.3	4.4	6.3
24	8.9	4.0	2.0	2.0

SOURCE: Lorri and Svanberg, 1988.

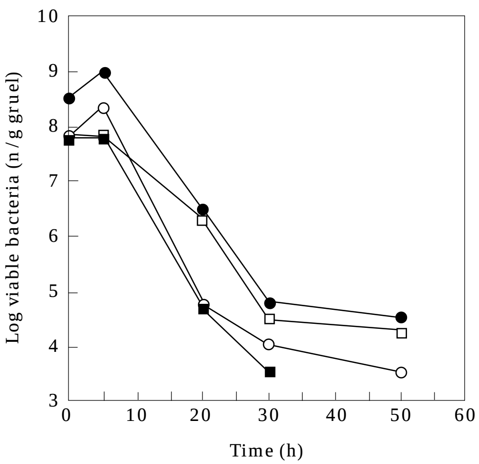

Figure 3. Evolution of pathogenic bacteria during the lactic fermentation of *uji*, a fermented cassava gruel (after Mbugua and Njenga, 1991). (□ = *Staphylococcus aureus*; ● = *Salmonella typhimurium*; ○ = *Escherichia coli*; ■ = *Shigella dysenteriae*.)

Alcoholic Fermentation of Cassava and Starch Products

Cassava is a potential producer of ethanol, considering its potentially high yields and low costs. Yet few reports concern the industrial application of cassava for ethanol production. This may be because, first, cassava cultivation yields relatively few, commercially significant byproducts, compared with, for example, sugarcane which yields enormous quantities of bagasse, a valuable source of energy for distillation. Second, cassava starch needs to be hydrolyzed into sugar for bioconversion into ethanol by the common *Saccharomyces cerevisiae*. This implies an additional, costly step.

For cassava to be an economically viable energy source, its processing costs must be reduced. Solid-state fermentation is one, simple, and new method of reducing costs: the use of an amylolytic yeast that eliminates hydrolysis.

At the ORSTOM Laboratory, Saucedo et al. (1992a; 1992c) developed a new process for the solid culture of an amylolytic yeast, *Schwanniomyces castelii* (Figure 4). The main advantage of this technique is its continuous recuperation of ethanol in a cold trap condenser. The gas produced in the reactor is pumped throughout the system, thus ensuring its continual removal from the medium and limiting its toxic effects on the yeast's metabolism. The results obtained by Saucedo et al. (1992a; 1992b; 1992c) were promising, but the technology and feasibility of the process for commercial operation need further research.

Table 6 shows the results obtained by various authors on the potential of cassava as a substrate for ethanol production. The solid-state technique has to be carefully considered. Results obtained with the fungus *Rhizopus koji* are particularly significant. The potential of *Schwanniomyces* is also interesting because amylolytic yeast would be easier to control at the small-scale industrial level.

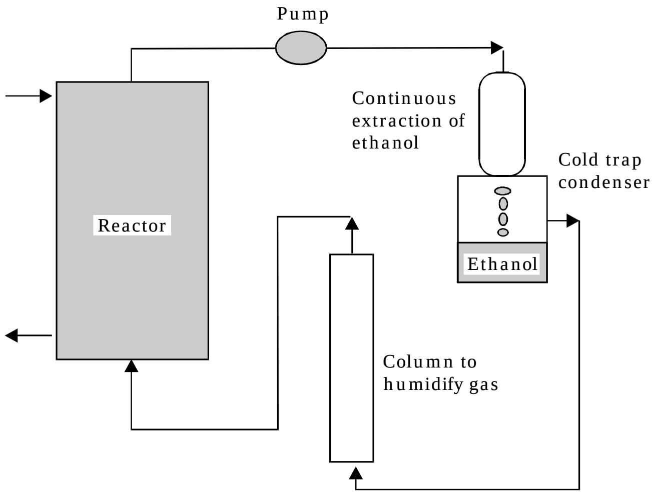

Figure 4. Producing ethanol through solid-substrate fermentation of cassava starch. The reactor contains a solid support impregnated with a starchy suspension and inoculated with the fermentation agent, an amylolytic yeast known as *Schwanniomyces castelii*. The resulting gas is pumped to a condenser where ethanol is extracted. The residual gas is sent to a humidifier.

Table 6. Comparison of various processes for ethanol production from cassava in liquid or solid substrate.

Process	Hydrolysis	Sugar (g/L)	Ethanol (g/L)	Recovered (g/L)	Theoretical (%)
Liquid substrate, using *S. cerevisiae* [a, b]	+	145	72.50	72.50	83.2
Solid substrate, using *S. cerevisiae* [b, c]	+	165	41.73	41.73	65.0
Solid substrate, using *Rhizopus koji* [d]	-	200	110.00	110.00	83.0
Solid substrate, using *Schw. castelii* [e, f]	-	300	68.40	212.60	64.0

a. Saraswati, 1988.
b. *S.* = *Saccharomyces*.
c. Jaleel et al., 1988.
d. Jujio et al., 1984.
e. Schw. = *Schwanniomyces*.
f. Saucedo et al., 1992a.

Conclusions on Bioconverting Cassava and Potential Products

To bioconvert cassava starch and flour to elaborate new products, ORSTOM, CIRAD, and collaborating institutes are emphasizing two approaches: solid-state fermentation, and lactic acid fermentation.

The first is of great interest because of its potential to simplify processes and reduce costs, and its large reactor volume. Both *Rhizopus* and *Schwanniomyces* (or other amylolytic) yeasts can be used in a solid-state cultivation process. This implies a three-phase reactor with a solid fiber support, a liquid phase containing the substrate in suspension and salts, and a gaseous phase for exchanging volatile components, that is, oxygen, water, and ethanol.

In lactic acid fermentation, we are investigating the culture control of amylolytic lactic acid bacteria in mixed and composite starters able to remain competitive in a natural, nonaxenic environment. The prophylactic role of lactic acid bacteria is also of great interest.

Finally, we are studying microorganisms able to degrade native cassava starches without need of gelatinization, as in in natural biotransformation and biodegradation. We will also study the amylolytic capacity of *Rhizopus* spp., yeasts, and lactic acid bacteria.

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CHAPTER 23

CASSAVA LACTIC FERMENTATION IN CENTRAL AFRICA: MICROBIOLOGICAL AND BIOCHEMICAL ASPECTS

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Summary

Retting is a lactic fermentation during which cassava roots are soaked for long periods in water. Despite the importance of this fermentation, no kinetic study of it has been undertaken. Our study therefore examined the biological and physical changes of cassava roots during retting to provide a basis for its possible mechanization.

The study was carried out to (1) enumerate and characterize the main microorganisms of the process; (2) determine the evolution of physicochemical parameters during retting; and (3) measure the production of organic products and some principal enzyme activities.

Retting can be characterized by three essential transformations of the roots: (1) a degradation of endogenous cyanogenic compounds (e.g., concentration decreased from 400 ppm in fresh cassava to 20 ppm in fermented mash); (2) a significant lysis of cassava cell walls due to the simultaneous action of endogenous pectin methylesterase and bacterial pectin lyase; and (3) the production of organic acids (C_2 to C_4), mainly lactate and butyrate, that contribute to the typical flavors of *chikwangue* and *fufu*.

In the study, most microflora involved in retting were facultative, anaerobic, fermentative bacteria, among which lactic bacteria were predominant. From the second day of fermentation, endogenous *Lactobacillus* species were totally supplanted by *Leuconostoc mesenteroides* and *Lactococcus lactis*. Anaerobic bacteria such as *Clostridium butyricum* were also found and seemed responsible for initiating butyrate production. Yeasts played no significant role, but their increasing number at the end of the process (*Candida* species) probably influenced the conservation of end products.

Despite the significant number of amylolytic bacteria (10^5-10^6 b/ml), the amylase activity found in the retting juice came from the roots and disappeared after 48 h of fermentation. The main enzymes of

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this process were cassava pectin methylesterase, bacterial pectinase, and endogenous linamarase.

The pH became stable at about 4.5 after 48 h and the partial oxygen pressure dropped to 0.2 mg/L after 10 h.

These results suggested that retting is a typical heterolactic fermentation with a significant production of butyrate.

Introduction

Processed cassava (*Manihot esculenta* Crantz) is eaten in West and Central Africa in such forms as *gari*, *lafun*, *fufu*, *chikwangue*, and tapioca. In the Congo, the world's second largest cassava consumer after Zaïre (Trèche, n.d.), cassava roots account for 47% of the calorie intake (Trèche and Massamba, n.d.b).

The two main products associated with fermented cassava are *fufu* and *chikwangue*. The former is a flour obtained from sun-dried cassava mash that is pulverized. This flour may be mixed with boiling water and served in bowls with sauce and fish or meat. *Chikwangue*, a cassava bread, is obtained after multiple postfermentation steps, including defibering and pugging (Trèche and Massamba, n.d.a).

Both products require a fermentation in which the roots soak for 3 to 6 days in tap water. During this process, cyanogenic compounds are eliminated, flavor compounds are elaborated, and the roots soften (Okafor et al., 1984; Oladele Ogunsa, 1980). Softening is indispensable for further root processing but the mechanisms involved are not yet fully understood.

Significant differences exist in retting processes throughout Central Africa and even in the Congo. Peeled or unpeeled roots are retted in rivers, standing water, large barrels of water, or even buried in soil. The fermentation temperature varies with season and location. Such differences, combined with the low reproducibility of the local processors, lead to a variability in quality and taste of cassava foods (Trèche and Massamba, n.d.a).

To increase the quality of these traditional products and provide a basis for the possible mechanization of the process, the European Union (EU) Program-STD2, known as "Improving the Quality of Traditional Foods Processed from Fermented Cassava" was set up in 1990 in Central Africa and South America. Our laboratory was to describe the mechanisms of root transformation during retting with a view to optimizing product quality and fermentation speed.

In this paper, we present the main results obtained during this EU program, describe the microbiological and biochemical evolution throughout the process, and define the origin (vegetal or microbial) of the main enzymes.

Material and Methods

Origin of plant material

Cassava roots (*Manihot esculenta* var. MM 86, or 'Ngansa') were harvested near Brazzaville, Congo, 18 months after planting.

Retting procedures

About 100 kg of washed and peeled roots were placed in a barrel and the volume made up to 50 L with rain water. A second barrel, filled only with rain water, was used as control for physicochemical measurements (T °C, pH, pO_2). Samples were taken every 12 h for the first 2 days and then every 24 h until retting was completed.

Sample preparation for bacterial enumeration

Sampling was carried out by randomly selecting six root sections, which were then cut into 0.5-cm cubes and mixed under sterile conditions. Of this mixture, 60 g were extracted and diluted in 540 ml of sterile, peptonized water (dilution 10^{-1}). The solution was then mixed in a Blendor (Turnmix ME 88, SOFRACA, France) and serially diluted in sterile, peptonized water for aerobic counts and in anaerobic Hungate tubes containing sterile, reduced water, flushed with 20% CO_2 and 80% N_2 for anaerobic counts.

Methods of bacterial quantification

Two types of enumeration were performed: “most probable number” (MPN) enumeration and plate counts on solid medium. The MPN method was used to either ascertain the growth of fermentative and pectinolytic bacteria or count the metabolites produced during growth on appropriate media for anaerobic, lactate-using bacteria. For each MPN determination, four successive dilutions of root samples were inoculated in three or four tubes per dilution. Results were calculated according to the McCready tables (McCready, 1918).

For plate counts, 0.1 ml samples of appropriate dilutions were inoculated in triplicate on agar medium in plates. All the plates were incubated at 30 °C and the number of colony-forming units determined after 48 or 72 h of incubation.

Bacterial enumeration

Lactic acid bacteria (l.a.b.). The l.a.b. were enumerated on MRS agar medium (de Man et al., 1960), supplemented with 0.1% of aniline blue. In each petri dish, 0.1 ml of appropriate root sample dilution was covered with medium and kept at 45 °C. Enumeration was carried out after a 48-h incubation at 30 °C. Subcultures were further purified by repeated plating.

Strains were differentiated into various bacterial groups by the following tests: microscopy examination, gram reaction, catalase test, and oxygen metabolism (fermentative or oxidative) test in soft MRS agar. Strains which were gram positive, catalase and oxidase negative, nonmotile rods or cocci, and colored by aniline blue were considered as lactic bacteria.

Glucose- and lactate-fermenting bacteria. These bacteria (g.f.b. and l.f.b., respectively) were enumerated on a basal medium that contained the equivalent of 2 g/L glucose or 5 g/L of lactate (used as a carbohydrate source); 0.5 g/L of trypticase and yeast extract; 0.5 g/L of cysteine HCl (used as a reductive agent); 0.1 g/L of sodium acetate; 0.005 g/L of resazurine; 20 ml of Widdel mineral solution (Widdel and Pfennig, 1984); and 1 ml of Widdel trace element solution (Widdel and Pfennig, 1984).

The Hungate technique (Hungate, 1969), modified for using syringes (Macy et al., 1972), was used throughout the study. After boiling, the medium was cooled under a continuous flow of oxygen-free N_2, adjusted to a pH of 7.2 with NaOH solution, and distributed anaerobically into Hungate tubes. The medium was sterilized for 35 min at 110 °C. Before inoculation, 1% of $Na_2S\text{-}9H_2O$ (5%) was added as a reductive agent to each tube. Inoculations were performed with syringes filled with oxygen-free N_2, using a gas manifold.

Yeast. A potato-dextrose agar medium (PDA, DIFCO Laboratory) was prepared, containing 0.05 g/L of chloramphenicol and with a final pH of 3.5, adjusted with tartaric acid (10%). The agar's surface was then dried. From an appropriate microbial dilution, 0.1 ml was spread, in triplicate, on plates containing the medium. The plates were then incubated for 72 h at 30 °C. Subcultures were further purified by repeated plating on PDA. Isolates were characterized to the genus level, and Api tests (API 5030 strips Biomerieux, France) were used to determine fermentation carbohydrate sources.

Physicochemical parameters

Penetrometry index. Penetrometry was used to indicate root softening during retting. A previous study showed that a penetrometry index of 15 mm/5 s corresponded to the end of retting as it is traditionally evaluated (Brauman et al., n.d.). A penetrometer (PNR 10-SUR, Berlin) was used to measure the consistency of the roots. Every 10 h, and for each experiment, six root sections were randomly chosen. Penetrometry depth was estimated with six repetitions for each root section.

The pH and partial oxygen pressure of the retting juice. Every 10 h, 50 ml of retting juice was extracted to test the pH (measured with CG 838 pH-meter from SCHOTT Geräte, Germany) and estimate partial oxygen pressure (measured with OXI 91 from WTW, Germany).

The pH and partial oxygen pressure of the roots. A 20-g sample was added to a Waring blender and mixed with 120 ml distilled water at low speed for 15 s and at high speed for 1 min. The mixture was then filtered through a GF/A filter and the volume made up to 200 ml with distilled water. Extracts were taken in duplicate at 0 h, 48 h, and at the end of retting. Acidity was titrated with 0.01 *M* NaOH.

Biochemical analysis

Enzyme assays. A sample of 40 g of cassava mash was added to a Waring blender, together with 80 ml of 0.1 *M* citrate buffer (pH = 6.5) and the mixture homogenized. The mixture was held overnight at 4 °C and centrifuged at 12,000 *g* for 30 min. The supernatant was lyophilized and resuspended in 1/10 volume of citrate buffer.

β-glucosidase activity. This was measured with a chromogen, *p*-nitrophenol-β-d-glucopyranoside, at 20 m*M* in 0.1 *M* of Na-phosphate buffer (pH = 6.8) for 1 h at 25 °C. The reaction was stopped by adding an equal volume of 0.2 *M* sodium borate (pH = 9.8), and *p*-nitrophenol was determined with a spectrophotometer at 400 nm (Hosel and Bartz, 1975).

Linamarase. This was assayed with linamarin as substrate and by measuring the appearance of CN^- (Giraud et al., 1992). To 400 µl of extract, 100 µl of 50 m*M* linamarin in 0.1 *M* citrate buffer (pH = 6.0) were added. At regular intervals, 50 µl aliquots were added to 50 µl of 0.1 *M* NaOH to stop the reaction, and stored at 4 °C. Cyanide was liberated by adding 50 µl of 0.1 *M* H_2SO_4 and 850 µl distilled water to each aliquot, and was measured with a spectroquant kit (Merck, Darmstadt, Germany). One unit of linamarase was defined as the amount of enzyme that released 1 μmol of CN^- per minute.

Activity of pectinesterase (PE; pectin pectylhydrolase, EC 3.1.1.11). This was assayed by titrating 1 ml of extract in 1% pectin at 30 °C (Grindsted RS400-DM 74%), and in 0.1 *M* NaCl and 1 m*M* NaN_3. pH was increased to 7.0 with 0.01 *M* NaOH. One unit corresponds to the neutralization of 1 μmol of COO^-/min.

Polygalacturonate lyase (PGL) activity. PGL activity was assayed by the Starr et al. (1977) procedure. This assay does not differentiate between endo-PGL (poly (1,4-α-d-galacturonide) lyase, EC 4.2.2.2) and exo-PGL (poly (1,4-α-d-galacturonide) exolyase, EC 4.2.2.9). One unit of PGL corresponds to the formation of 1 μmol of one unsaturated bond in galacturonide between C4 and C5.

Polygalacturonase (PG; poly (1,4-α-d-galacturonide) glycanohydrolase, EC 3.2.1.15). This was assayed by viscometry. To 40 ml of 1% pectin in 100 m*M* of acetate buffer (pH = 4.7), 0.5 ml of extract was added. The rate of reduction in viscosity was measured at 25 °C in a viscometer (Haake model; VT 500, rotation: 150.93 s^{-1} and system MV-MV1). One unit corresponds to the release of 1 μmol of hexose/min. Total activities are expressed as units per 100 g of cassava.

Action of pectic enzymes in vivo. Sterilized slices of cassava were inoculated with 50 μl of enzyme extract or 5 μl of purified pectolytic enzymes (endopolygalacturonase P-5146 from *Aspergillus niger*; pectolyase P-3026 from *A. japonicum*; and pectinesterase P-0764 from orange peel) (Sigma, Saint-Quentin Fallavier, France). The inoculated slices were placed in sterile beakers containing 10 ml of 0.01 *M* of citrate buffer (pH = 5.0). Penetrometer readings were estimated after 24 h and 48 h at 30 °C.

Cellulase, amylase, and xylanase activities. These activities were also assayed at 37 °C and pH of 5.8, using the Somogyi procedure (Somogyi, 1945). The substrates were microcrystalline cellulose (100 mg) and xylan (18 mg/ml).

Other analytical methods

Total and free cyanides were assayed by the Cooke et al. method (1978). Protein was determined with a modified Lowry procedure (Bensadoun and Weinstein, 1976).

Organic compounds

Sugars, volatile fatty acids (VFA), and lactate and ethanol concentrations in the roots were determined by high-performance liquid chromatography (HPLC) of the supernatant, as described by Giraud et al. (1991). The resulting columns (BioRad Laboratories, Richmond, California) were:

(1) Fast carbohydrate column for monosugars analysis (100 x 7, 8 min) with 0.6 ml flow of milliQ water (pH = 6.0) at 70 °C;
(2) Aminex HP 42 A (300 x 7.8 min Biorad) for polyosides analysis with 0.3 ml flow of milliQ water (pH = 6.0) at 70 °C;
(3) Aminex HP x 87H column with 0.8 ml/min flow of H_2SO_4 6 m*M* at 60 °C.

Results and Discussion

Kinetic studies of retting

We now present the results of our global study of lactic fermentation. Kinetic parameters such as total and fermentative microflora, physicochemical parameters, and

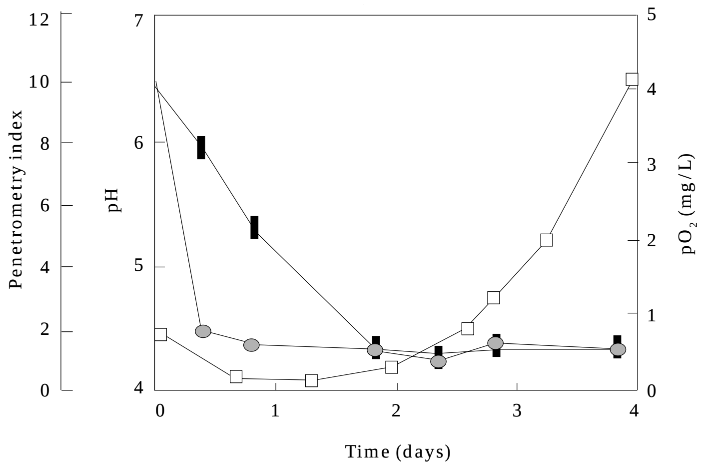

Figure 1. The evolution of physicochemical parameters during retting. (▮ = pH; ⬭ = pO_2; □ = penetrometry index.)

substrates and metabolites produced have been measured throughout the process. These results are the mean of seven rettings performed in barrels under the same conditions.

Evolution of physicochemical parameters

The main physicochemical parameters were assayed throughout the process (Figure 1). The partial oxygen pressure dropped to well below 1 mg/L after 10 h and the pH became stable (at 4.5) within 48 h. Conversely, root softening, indicated by the penetrometry index, appeared after 2 days of fermentation and evolved exponentially. This process seems to require anaerobic and acidic conditions to proceed. Microscopic examination shows that the cassava cell walls were extensively disrupted at the end of the process, demonstrating the attack of depolymerizing enzymes.

The concentration of endogenous cyanogenic compounds decreased from 300 mg/kg as HCN (dry matter basis) in fresh cassava to 20 in the fermented mash (Figure 2). In all assays, total cyanogens were almost eliminated (90%). These results demonstrated that, under the standard conditions of local transformations in Central Africa, detoxification occurred normally without need of an additional process.

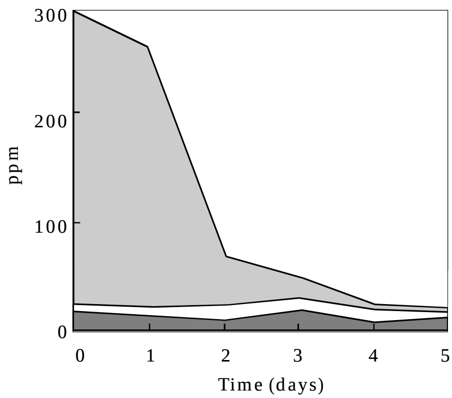

Figure 2. Total cyanide evolution. (▢ = linamarin; □ = cyanhydrines + free cyanides; ■ = free cyanides.)

Evolution of substrates and metabolites

The main substrates degraded (Figure 3) were oligosaccharides (fructose, glucose, and saccharose). The low level of polyosides generated by starch degradation (e.g., maltotriose and maltose) underline the weak degradation of the starchy mass during retting. Saccharose seems to be the main substrate degraded by the fermentative microflora.

The main organic acid produced was lactate. However, significant levels of ethanol, acetate, and butyrate were also found (Figure 4). They seem to be generated mostly by the heterolactic fermentation of the oligosaccharides present in the cassava roots, except for butyrate, which could have come from an anaerobic fermentation mediated by *Clostridium* species. Butyrate concentration could vary from 0.4 to 2.5 g/100 of dry matter in different fermentations carried out under the

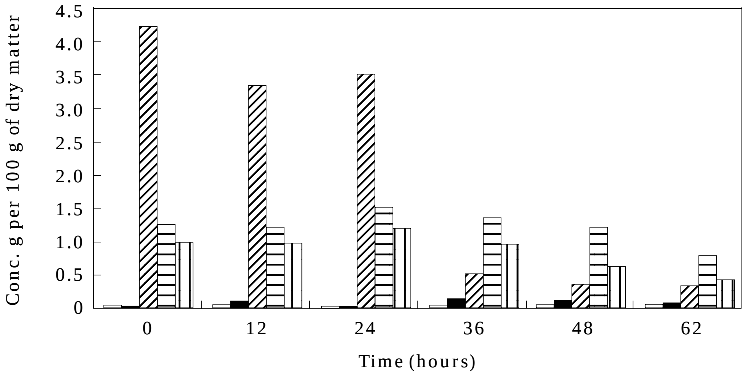

Figure 3. Oligo- and monosaccharide evolution during retting. (□ = maltotriose; ■ = maltose; ▨ = saccharose; ☰ = glucose; ▥ = fructose.)

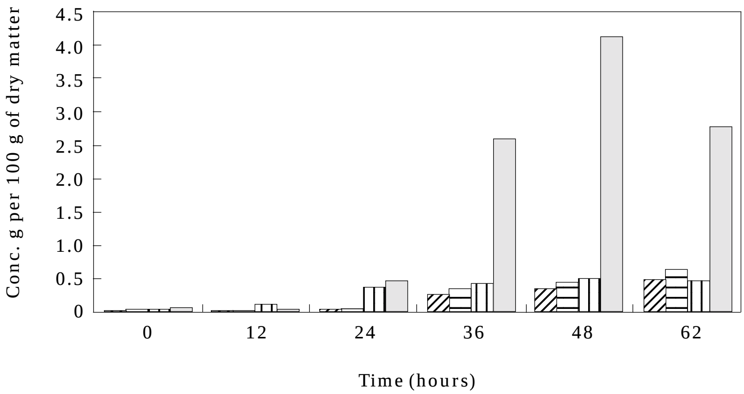

Figure 4. Organic acids and alcohol evolution during retting. (▨ = butyrate; ☰ = ethanol; ▥ = acetate; □ = lactate.)

same conditions. Because of their organoleptic qualities, butyrate and lactate seem to be the most typical products of this process.

Microflora evolution

Fermentative and lactic microflora. In the enumerations, only fermentative bacteria were counted because retting was seen as largely anaerobic (Figure 1). The fermentative microflora evolved during the first 2 days of fermentation and remained stable to the end. The total fermentative microflora represented by the glucose-fermenting bacteria was dense, reaching 10^{12} b/g after 48 h of fermentation. The next most predominant flora were the l.a.b. (Figure 5), reaching 10^4 to 10^8 b/g of DM on fresh roots. The variation of endogenous l.a.b., composed mainly of *Lactococcus* and heterolactic *Lactobacillus* species, did not influence the evolution of l.a.b. during fermentation.

Lactate-fermenting bacteria. One metabolite formed during fermentation is butyrate (Figure 4). This compound is a typical product of carbohydrate fermentation by anaerobic spore formers (*Clostridium* species). To evaluate this population, enumeration was done anaerobically on lactate because (1) lactate is the major substrate found in retting; and (2) it is not used as a substrate by the l.a.b. Surprisingly, the results of this enumeration showed that the population of lactate-fermenting bacteria remained constant and at low levels (10^3 b/g of DM) throughout the retting (Figure 5). The presence of butyrate and acetate in the positive tubes, and the isolation of strictly anaerobic, sporulating, gram-positive rods with the same fermentation pattern as *Clostridium butyricum*, confirmed that *Clostridium* species are present in retting. However, their role in the process remains to be studied because of their reduced numbers in the enumeration and lactate does not seem to be their natural substrate in retting.

Yeasts. The only flora that appeared after 48 h of fermentation and still developed until the end of retting were yeasts. Their metabolisms allow them to grow at the low pH imposed by the l.a.b. Their numbers remained low during the fermentation (about 10^3 b/g of

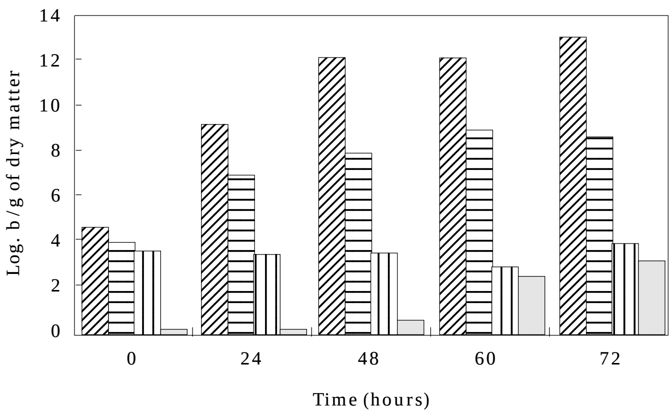

Figure 5. Evolution of fermentative microflora during retting. (▨ = glucose-fermenting bacteria; ☰ = lactic acid bacteria; ▥ = lactate-fermenting bacteria; ☐ = yeast.)

DM), suggesting that they do not play a significant role in retting. When the retting finished, the yeasts covered the entire water surface and became the main flora of the postretting stage. Their increasing numbers at the end of the process (mostly *Candida* species) may therefore influence the conservation of end products.

Origin of enzymes involved in retting. The main enzymes found in this process were pectinase and linamarase, and to a lesser extent, amylase (data not shown). No cellulase or xylanase activities were found in retting. To elucidate the origin of cyanogen elimination and the mechanism of root softening, two fermentations were carried out simultaneously: one "natural," used as a control (CF), and one sterile (SF). pH and oxygen pressure of SF were set on those of CF. Pectinase and linamarase activities were assayed throughout the experiment. For SF, cassava roots were sterilized with $HgCl_2$ and soaked in sterile water.

Origin of softening. No softening was obtained in sterile fermentation (Figure 6). High endogenous pectin methyl esterase activities were found in cassava extracts from both fermentations (Figure 7). Depolymerizing enzymes, endopolygalacturonase (active at low pH), and pectate lyase were found only in the "natural" fermentation (Figures 8 and 9). No other depolymerizing enzymes, such as cellulase or xylanase, nor other hydrolases were found. Moreover, softening could be performed by inoculating commercial pectinesterase and depolymerizing pectolytic enzymes on fresh and sterile cassava roots.

We suggest, therefore, that root softening is a result of the combined action of both endogenous pectin methyl esterase and exogenous bacterial depolymerizing enzymes. But further studies are needed to show the precise contribution of each pectic enzyme to root softening.

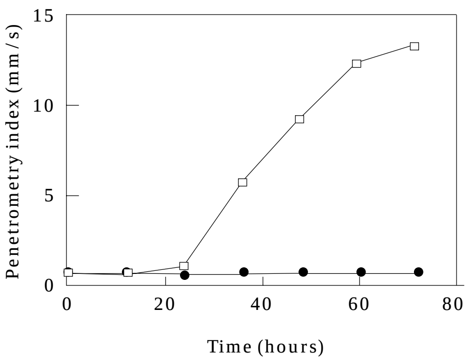

Figure 6. Comparative evolution of softening between a sterile (●) and a natural retting (□).

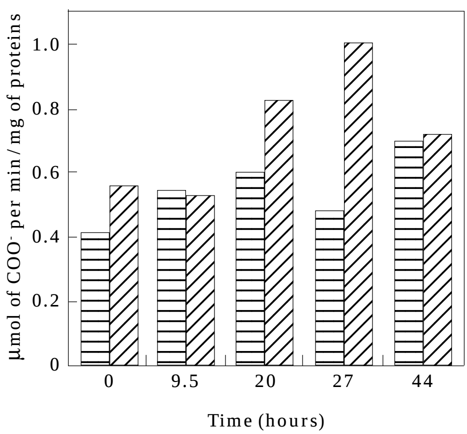

Figure 7. Pectinesterase activity during retting. (▤ = sterile fermentation; ▨ = control fermentation.)

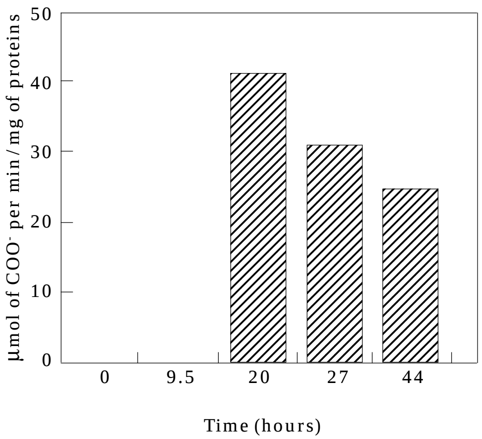

Figure 8. Pectate lyase activity during "natural" fermentation.

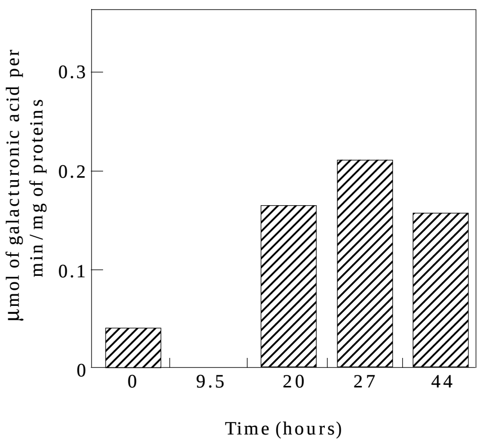

Figure 9. Endopolygalacturonase activity during "natural" fermentation.

Origin of cyanogen elimination. Of total cyanogenic compounds, 50% were eliminated in SF and 97% in CF (Figure 10). Enzyme assays further confirmed endogenous linamarase activity (Table 1). Linamarase activity (measured as β-glucosidase activity) in CF was significant in fresh roots (specific activity 9.4 units/mg protein). This total activity then decreased after a few hours. In SF, total activity remained constant, but at a low level. The difference in β-glucosidase activity in the fresh roots between SF and CF may be attributed to the inhibitory effect of the $HgCl_2$ used to sterilize the roots. However, as nearly 25% (Table 1) of the total β-glucosidase activity present in the sterile roots can degrade more than 50% of the total cyanide content of the fresh roots, we can assume that the level of linamarase activity present in the intact roots was sufficient to detoxify the roots.

Origin of the amylolytic activity. The amylase activity remained constant in SF, but disappeared after 36 h of fermentation in CF (Figure 11). Our data suggest that the amylase activity detected in retting does not have a bacterial origin as suggested by different authors (Collard and Levi, 1959; Oyewole and Odunfa, 1992; Regez et al., 1987).

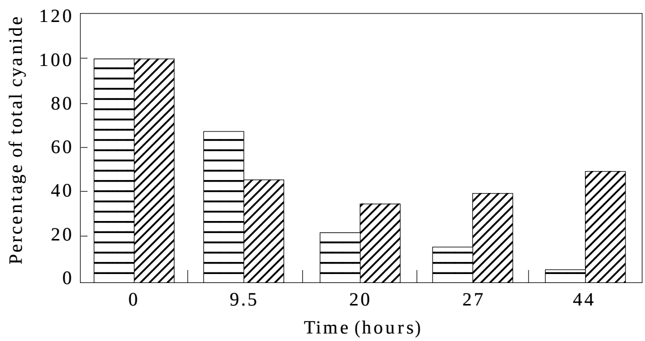

Figure 10. Total cyanide evolution in control (▤) and sterile (▨) fermentations.

Table 1. β-glucosidase activities in control and sterile fermentations. (Activities are expressed in mmol per min/100 g of dry matter).

Time (h)	Fermentation	
	Control	Sterile
0	9.12	2.15
9.5	5.58	2.55
20.0	6.10	1.75
27.0	7.68	2.30
44.0	7.24	1.38

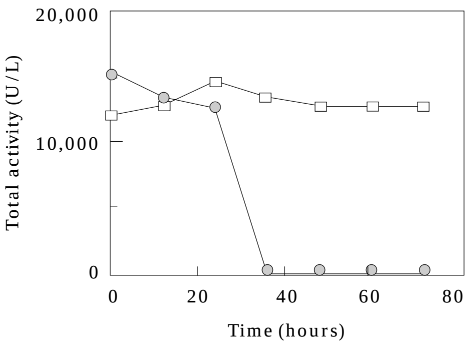

Figure 11. Amylase activity in control (◎) and sterile (□) fermentations.

Conclusions

These results suggest that retting is a complex heterolactic fermentation, with an interaction between lactic bacteria, *Clostridium* species, and possibly *Bacillus* species. Heterolactic bacteria (such as *Leuconostoc mesenteroides*) are the most important and numerous microflora in the process; they are responsible for the physicochemical properties of retting (e.g., pO_2 and pH) and the production of the main organic acids (acetate and lactate). *Clostridium* species seem to be involved in butyrate formation, which is essential for the organoleptic properties of the final products. Moreover, recent results (S. Kéléke, 1994, personal communication) suggest that *Clostridium* species (such as *Clostridium butyricum)* could be involved with *Bacillus* species (such as *Bacillus polymyxa*) in root softening as pectinase producers. We did not see any involvement of *Geotrichum* spp. or *Corynebacterium* spp., as have other authors (Collard and Levi, 1959; Okafor et al., 1984; Regez et al.,1987). Yeasts (mostly *Candida* species) were more involved in postretting.

Our biochemical analyses showed that retting is a fermentation in which both endogenous and microbial enzymes coact to soften the roots and degrade cyanogenic, endogenous compounds. Our results suggested that cell-wall degradation is initiated by endogenous pectinesterase, located in intercellular spaces and released by pH decrease. This is followed by microbial polygalacturonase and lyase depolymerizing pectic chains. The presence of pectic enzymes in cassava retting has previously been reported (Okafor et al., 1984; Oyewole and Odunfa, 1992). But this work gives the first evidence of the vegetal origin of pectinesterase and of the in vivo activity of depolymerizing enzymes.

The amylase activity measured in retting seems to be of vegetal origin. But its low level of activity and disappearance within the first 30 h of retting suggest that it is not important to the retting process.

Results of cyanide measurements indicate that endogenous linamarase (measured as β-glucosidase activity) is the main enzyme responsible for detoxification. We can assume, as Maduagwu (1983) suggested, that the level of linamarase activity present in intact roots is sufficient to detoxify them of their cyanogen content without help from any microbial linamarase. Nevertheless, if bacteria do not directly detoxify cassava roots, they could help degrade linamarin by destroying cell walls.

Findings from our study have helped other researchers:

(1) Isolate and characterize the first amylolitic *Lactobacillus plantarum* (strain A6) (Giraud et al., 1991);
(2) Improve *fufu* processing by significantly reducing retting time, and increase the organoleptic qualities of the final product (Ampe et al., 1994);
(3) Adapt the process for areas with low water availability (Miambi et al., n.d.).

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CHAPTER 24

A LACTIC ACID BACTERIUM WITH POTENTIAL APPLICATION IN CASSAVA FERMENTATION

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Abstract

An amylolytic lactic acid bacterium, identified as *Lactobacillus plantarum*, was isolated from cassava roots (*Manihot esculenta* var. Ngansa) during retting. Cultured on starch, the strain displayed a growth rate of 0.43 per hour, a biomass yield of 0.19 g/g, and a lactate yield of 0.81 g/g. The growth kinetics were similar on starch and glucose. Enough enzyme was synthesized, and starch hydrolysis was not a limiting factor for growth. The synthesized amylolytic enzyme was purified by fractionated precipitation with ammonium sulfate and by anion exchange chromatography. It was identified as an α-amylase with an optimal pH of 5.5 and an optimal temperature of 65 °C. The use of such a strain as a cassava fermentation starter for *gari* production had the following effects: a change from a heterofermentative pattern observed in natural fermentation to a homofermentation one, a lower final pH, a faster pH decline rate, and a greater production of lactic acid (50 g/kg of dry matter).

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Introduction

Lactic microflora play an important role in the preparation of traditional foods based on fermented cassava, such as *gari*, *chikwangue*, *fufu*, and sour starch. But this microflora's function in preserving foods, eliminating cyanogenic compounds, and improving organoleptic qualities is not yet clear. Traditional technologies are still used to manufacture these foods. As fermentation occurs naturally with lactic microflora, the quality of the food products is not uniform.

The mass inoculation of cassava roots with one or several selected strains would permit a better control over natural fermentation, thus resulting in a product of improved quality. Because cassava contains mainly starch (more than 80% of dry matter), the selection of a lactic acid bacterium capable of metabolizing starch (i.e., amylolytic) is essential.

But few lactic acid bacteria can convert starch into lactic acid. Examples of amylolytic lactic acid bacteria are *Streptococcus bovis*, *S. equinus*, *Lactobacillus amylophilus*, *L. amylovorus*, *L. acidophilus*, *L. cellobiosus*, and others isolated from animal digestive tracts and plant wastes (Champ et al., 1983; Cotta, 1988; Nakaruma, 1981; Nakaruma and Crowell, 1979; Sen and

Chakrabarty, 1986; Sneath, 1986). Almost no information exists on the physiology of these microorganisms.

Below we describe how we isolated and identified a new amylolytic lactic acid bacterium from fermenting cassava roots. We also investigated the physiology of this bacterium and the properties of the amylase produced.

Methods

Isolating and identifying strains

Peeled roots were immersed in rain water. Sampling was carried out 4 days after fermentation by randomly selecting six roots cut into 0.5-cm cubes and mixed under sterile conditions. A sample of 60 g was diluted in 540 ml of sterile peptone solution. Then 0.1 ml of decimal dilutions were spread on JP2 medium (see below) in petri dishes. After incubation for 48 h at 30 °C, the dishes were exposed to iodine vapor to detect the starch hydrolysis areas. Isolated strains were then purified by three successive transfers on JP2 medium, and cultures routinely checked for purity by microscopic observation.

Microorganisms were identified by:

(1) the configuration of the lactic acid produced after treatment (Ivorec-Szylit and Szylit, 1965) with the enzymes dehydrogenase l and d (Boerhinger Mannheim);
(2) the microorganisms' homolactic or heterolactic character, as determined by acetic acid or
(3) presence or absence of catalase;
(4) microscopic and macroscopic examination of morphology, mobility, and spores;
(5) Gram stain;
(6) arginine dissemination;
(7) growth at 15 and 45 °C; and
(8) fermentation of different carbon sources (API 50CH #5030 strips, Biomérieux, France).

"Bergey's Manual" (Sneath, 1986) was used to evaluate results and identify the different strains.

Strains and culture media

Three strains were used as reference: *Lactobacillus plantarum* (Lacto Labo, France), *Streptococcus equinus* CNCM 103233, and *Lactobacillus amylophilus* CNCM 102988T.

JP2 medium (g/L). This consisted of:

M66 universal peptone	2.5
Soya peptone obtained by papain digestion	5
Casein peptone obtained by pancreatic digestion	2.5
Yeast extract	5
Meat extract	2.5
$MgSO_4$,$7H_2O$	0.1
NaCl	3
$(NH_4)_2SO_4$	2
K_2HPO_4	0.2
Prolabo soluble starch	3
Tween 80 (in ml)	0.4

The pH was adjusted to 6.75 before sterilization.

Physiological studies were performed, using a de Man-Rogosa-Sharpe (MRS) basal medium (de Man et al., 1960) and changing the carbon sources to 5% glucose and 5% starch.

Culture conditions. Strains were cultured in a 2-L bioreactor (Biolafitte, France) at 30 °C and agitated at 200 rpm. The pH was adjusted to 6.0 by adding NaOH (5 *N*). Inoculation at 10% v/v was performed with a 20-h pre-culture in the same medium used for fermentation.

Analytical methods

The biomass concentration was determined by measuring the optical density (OD) at 540 nm related to the dry weight measured after two washing and centrifugation cycles and drying at 105 °C for 24 h. For starch cultures, hydrolysis of residual starch was performed with a mixture of amylases (thermamyl + dextrosyme, supplied by Novo). The dry weight and OD were then determined as above. Lactic acid, glucose, acetic acid, and ethanol concentrations in the supernatant were assayed by high-performance liquid chromatography (HPLC). Compounds were separated by using an Aminex HPX 87H column (Bio Rad Laboratory) with a 0.8 ml/min flow (pump LDC 3200) of H_2SO_4 (0.012 *N*) solution at 65 °C. Analyses were carried out with a refractive index detector (Philips PU 4026). Total sugars in media containing starch were also determined with anthrone, using the Dubois et al. (1956) method.

Amylase assay. The α-amylase activity was measured by incubating 0.1 ml of appropriately diluted enzyme solution with 0.8 ml of a solution containing 1.2% of Prolabo soluble starch in 0.1 mol/L citrate-phosphate buffer (pH = 5.5) at 55 °C. The reaction was stopped by adding 0.1 ml of 1 mol/L H_2SO_4. After incubation, residual starch contents were determined colorimetrically after different periods at 620 nm by adding 0.1 ml of the reaction mixture to 2.4 ml of an iodine solution containing 30 g/L of KI and 3 g/L of I_2 and diluted to 4% with distilled water.

An enzyme unit is defined as the amount of enzyme that permits the hydrolysis of 10 mg of starch in 30 min under the conditions described above. Protein concentration was estimated with the Bradford (1976) method, using a Biorad Kit (Cat No. 500-0001, Ivry-sur-Seine, France) and bovine serum albumin as standard.

Purification of amylase. Fermentation was stopped after culture for 9 h. Cells were removed by centrifugation (at 15,000 g for 15 min at 4 °C), and the supernatant fluid (750 ml) filtered through a cellulose filter (0.45 µm pore size, HAWP type, Millipore, Saint Quentin les Yvelines, France) to remove cell debris.

Powdered ammonium sulfate was then slowly added to the supernatant fluid under constant stirring at 4 °C. Most of the amylase activity was precipitated at between 50% and 70% saturation.

After the ammonium sulfate fractionation, the precipitated protein collected by centrifugation (at 15,000 *g* for 30 min at 4 °C) was resuspended in 50 mmol/L KH_2PO_4/ Na_2HPO_4 standard buffer (pH = 6.8). The enzyme solution was washed and concentrated with a PM-10 Amicon ultrafiltration membrane. It was then loaded onto a diethylaminoethyl (DEAE) cellulose column (DE-52; Whatman Laboratory Sales, Hillsboro, Oregon, USA). The column (25 x 250 mm, flow rate 2.5 ml/min, 25 °C) was previously equilibrated with the standard buffer. The enzyme was eluted, using a concave, sodium chloride gradient (0-1.0 mol/L). Fractions (5 ml) were collected. The fractions that were enzymatically the most active were pooled, dialyzed overnight at 4 °C against the standard buffer, and used for further studies. They were kept at -30 °C. No activity was lost for at least 3 months under such conditions.

Polyacrylamide gel electrophoresis. This was carried out according to Laemmli's method (1970), with a 10% running gel and 4%

stacking gel. Electrophoresis under nondenaturating conditions was performed in the absence of sodium dodecyl sulfate (SDS) and β-mercaptoethanol in any buffer. Gels were run at a constant 150 V for 1 h at 25 °C. Proteins were stained by the silver method (Oakley et al., 1980).

Amylase stain. After electrophoresis, gel was incubated for 1 h at 30 °C in 0.1 mol/L citrate-phosphate buffer (pH = 5.5), containing 1% of soluble starch. After two washes with distilled water, light lanes (representing starch hydrolysis areas of amylase activity) were detected by immersing the gel in Lugol's solution.

Molecular mass determination. SDS-PAGE electrophoresis was used to determine the approximate molecular mass of amylase. Marker proteins (Biorad, Cat. No. 161-0315) used were myosin (200,000), β–galactosidase (116,250), phosphorylase-b (97,400), bovine serum albumin (67,000), and ovalbumin (45,000).

Assays on gari. Fresh imported cassava roots from Cameroon were obtained from Anarex (Paris, France). *Gari* was prepared from peeled, washed cassava roots, which were chopped and minced in a food mixer (SEB). The pulp obtained was packed tightly into plastic, sterile, screw-capped containers (60 ml; OSI, A12.160.56) and placed at 30 °C.

Three batches were prepared: (1) natural fermentation, using the endogenous microflora present; (2) fermentation after inoculation with *L. plantarum* A6 (10^8 cfu/g of dried cassava), which had been cultured in bioreactors on cellobiose MRS medium; (3) fermentation after inoculation with *L. plantarum* Lactolabo (10^8 cfu/g of dried cassava), which had been cultured in bioreactors on MRS cellobiose. Cells were washed in physiological solution before cassava inoculation.

A container from each batch was monitored every day to test the following parameters:

(1) The pH was measured on a 10-g sample and homogenized in distilled water (20 ml). Moisture was measured by drying a 10-g sample at 105 °C for 24 h.
(2) The number of lactic acid bacteria (l.a.b.) was estimated on a 10-g sample homogenized in 90 ml of physiological sterile solution. Colonies were counted on MRS agar, using a spread-plate technique on petri dishes and after incubation at 30 °C and 48 h.

Results and Discussion

Isolation and identification of **Lactobacillus plantarum** *A6*

Seven amylolytic microorganisms were isolated on JP2 medium from retted cassava roots. Two were revealed by HPLC to have a capacity to produce lactic acid from starch. Table 1 lists their morphological, physiological, and biochemical characteristics. The ability of these cultures to use 49 different carbohydrates was studied with API 50CH #5030 strips. The results were compared, by computer, with the percentage of positive reactions of different *Lactobacillus* species as per API. A 99.9% rate of similarity with *L. plantarum* was observed and hence identifying these cultures as strains of *L. plantarum*. The two strains, A6 and A43, displayed precisely the same sugar degradation profiles, which suggests that they are probably the same.

The amylolytic activities on JP2 medium of *L. plantarum* A6, *S. equinus*, and *L. amylophilus* indicated that the

Table 1. Characteristics of *Lactobacillus plantarum* strains A6, A43, and Lacto Labo (check).

Strain	A6	A43	Check
Ratio of d:l lactic acid	69:31	66:34	73:27
Homolactic	+	+	+
Catalase	-	-	-
Bacterium shape	Short rod	Short rod	Short rod
Gram stain	+	+	+
Spore	-	-	-
Mobility	-	-	-
Dissemination of arginine	-	-	-
Growth at 15 °C	+	+	+
Growth at 45 °C	-	-	-

starch hydrolysis zone was largest for *L. plantarum* A6. It was therefore selected for further studies.

Lactobacillus plantarum *A6 growth kinetics*

The growth of *L. plantarum* A6 on glucose MRS medium (Figure 1) is fully comparable with that of *L. plantarum* (Lacto Labo). The growth rate (0.43/h) and biomass productivity (0.75 g/L per hour) were slightly lower than those of the standard (Lacto Labo) strain, but the biomass and lactate yields were almost identical. The strain therefore does not seem to require nutrients other than those of the common strain, suggesting that mass production is possible.

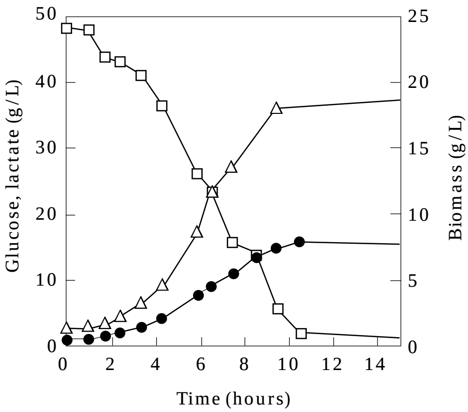

Figure 1. Fermentation of *Lactobacillus plantarum* A6 on MRS glucose (□ = glucose; △ = lactic acid; ● = biomass). Temperature = 30 °C; pH = 6.0.

On starch MRS medium, the strain exhibits the same kinetic profiles (Figure 2) and the same yields as the standard strain. The rate of starch hydrolysis was greater than the uptake rate, leading to a 3 g/L maltose peak during the seventh hour of fermentation (results not shown). Thus, hydrolysis of starch is not a limiting factor.

Characterizing the amylolytic enzyme

To characterize the amylolytic activity exhibited by *L. plantarum* A6, a comparison was made of the HPLC profiles after starch hydrolysis by the cell-free extract and commercial amylolytic enzymes (*Aspergillus oryzae* α-amylase, Sigma A0273; potato β-amylase, Sigma A7005, and *Aspergillus niger* amyloglucosidase, Sigma A3514). Under these conditions, the main products of starch hydrolysis analyzed by HPLC were glucose from amyloglucosidase, maltose from β-amylase, and a mixture of glucose, maltose, and oligosaccharide (retention time of 5.2 min) from α-amylase. The

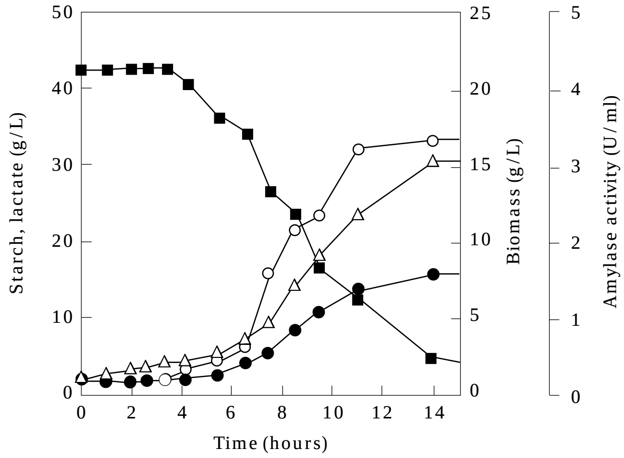

Figure 2. Fermentation of *Lactobacillus plantarum* A6 on starch MRS medium (■ = starch ; △ = lactic acid; ● = biomass; ○ = amylase activity). Temperature = 30 °C; pH = 6.0.

breakdown profile of starch by the enzyme from *L. plantarum* A6 is similar to that of α-amylase, thereby indicating that the enzyme synthesized by *L. plantarum* A6 is extracellular α-amylase.

Purification of amylase

The results of purifying the amylase produced by the strain *L. plantarum* A6 are summarized in Table 2. The first step in purification was conventional $(NH_4)_2SO_4$ fractionation. The 50%-70% fraction revealed maximum enzyme activity and was selected for further purification by DEAE-cellulose. The elution profile displayed only one amylase activity peak. The purification procedure described above makes it possible, in only two stages, to obtain a protein fraction containing most of the amylase activity of *L. plantarum* A6 enriched by a factor of nearly 20.

Testing the homogeneity of the fraction by electrophoresis under native conditions revealed a major protein and three others that were quantitatively unimportant. However, all the proteins detected in the purified fraction possessed an amylase activity. These procedures were therefore considered sufficient for purifying the extracellular amylase activity of *L. plantarum* A6. The SDS-PAGE analysis of the purified fraction resulted in a distribution between a clearly defined band (50 kDa) and a diffuse band with a molecular weight of close to 150 kDa.

Hypotheses. Several hypotheses can explain these many amylase forms. We find the most satisfactory is that which suggests that the purified extract consists of a population of aggregates of a 50-kDa amylase. This interpretation is based on the fact that most of the bacterial amylases described have a molecular weight of this order (Fogarty, 1983). This type of aggregation of purified enzyme was observed in *Bacillus subtilis* amylase (Robyt and Ackerman, 1973), with zinc being the factor inducing clumping. The clumping factor remains to be defined in our case.

Further study is needed to support this hypothesis. The

Table 2. Purification of α-amylase of *Lactobacillus plantarum* strain A6 cultivated in a modified MRS medium containing 2% (w/v) soluble starch and 0.5 g/L $CaCl_2$ at 30 °C.

Materials	Volume (ml)	Protein (mg)	Activity (U)	Specific activity (U/mg)	Yield (%)	Purification (fold)
Culture filtrate	750.0	82.5	35100	425	100.0	1.0
$(NH_4)_2SO_4$ (50%-70% fraction)	39.0	18.1	25935	1433	73.9	3.4
Ultrafiltrate	8.8	10.4	16016	1540	45.6	3.6
DEAE-cellulose (117-130 fractions)	61.8	1.5	12484	8270	35.6	19.5

amount of enzyme isolated was not large enough for further investigation. Immunological characterization would probably determine the type of relation between the different amylase forms observed and thus confirm the hypothesis.

Effects of pH and temperature on amylase activity. The effect of pH on enzyme activity was studied in a 3.0 to 7.5 pH range with 0.1 mol/L citrate-phosphate buffer at 55 °C. The enzymatic activity profile according to temperature was determined within a 10 to 80 °C temperature range under standard conditions (see above). The optimal pH was 5.5 and the optimal temperature was 65 °C (Figures 3 and 4).

Compared with the characteristics of the lactic acid bacterial amylases described in the literature, the properties of the enzyme synthesized by *L. plantarum* A6 are different. The enzyme from a *Leuconostoc* spp. studied by Lindgren and Refai (1984) had a pH optimum of 6.0 and a temperature optimum of 40 °C. Two active enzyme fractions were clearly separable by isoelectric focusing. The enzyme isolated from *L. cellobiosus* (Sen and Chakrabarty, 1986) had a molecular weight of 22.5 to 24 kDa, a pH optimum from 6.3 to 7.9, and a temperature optimum of 40 to 50 °C. But the characteristics of the amylase from *L. plantarum* A6 are very similar to those of *Bacillus subtilis* (Fischer and Stein, 1960; Fogarty, 1983; Robyt and Ackerman, 1973; and Welker and Campbell, 1967): extracellular enzyme, identical optimal pH (5.5), identical optimal temperature (65 °C), presence of tyrosyl phenolic groups at the active site, and presence of multiple forms (aggregates).

We speculated that the exceptional capacity of *L. plantarum* A6 to break down starch might have

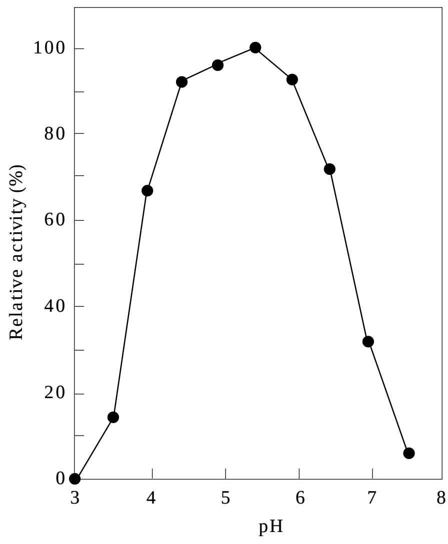

Figure 3. Effects of pH on amylase activity at 55 °C.

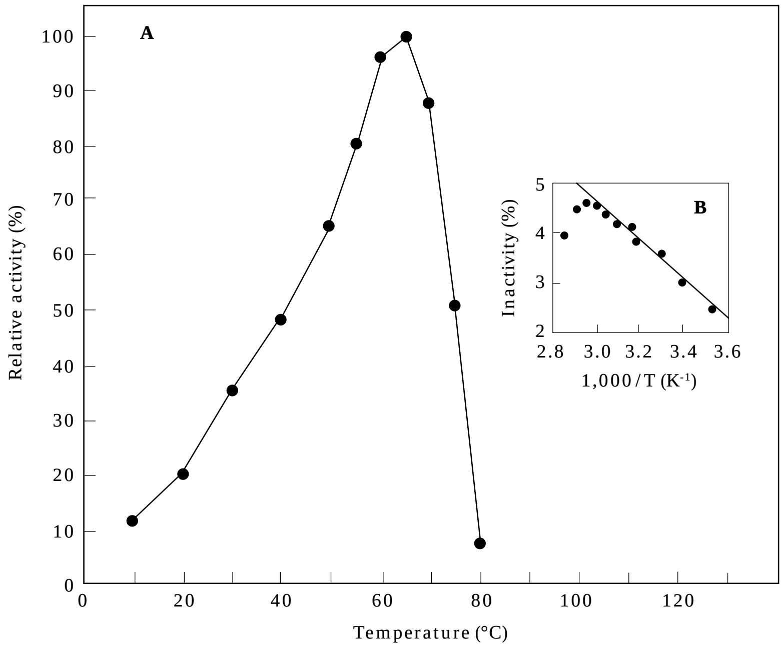

Figure 4. Effects of temperature on amylase activity at pH = 5.5. (A) Relative activity versus temperature; (B) Arrhenius plot.

been a result of transfer of genetic material between *Bacillus subtilis* and *L. plantarum*, which could be possible, because both are microorganisms found in the natural microflora of fermented cassava (Nwanko et al., 1989), and whose amylase activities are very similar. Further investigation would answer this question.

Inoculation effect of **Lactobacillus plantarum** *A6 on cassava fermentation*

Three different assays were carried out: (1) natural cassava fermentation, (2) cassava inoculated with *L. plantarum* A6, and (3) cassava inoculated with a control strain, *L. plantarum* Lacto Labo.

Evolution of pH, organic acids, and lactic acid bacteria. In all three assays, a rapid pH decrease was observed from the start of fermentation (Figure 5). The naturally fermented cassava showed a steep fall from 6.2 to 4.3 (assay 1), and both inoculation assays (2 and 3) from 6.2 to 3.9. This pH shift was correlated with lactic acid production, which was the principal metabolite produced (Figure 6). These data confirm that the lactic acid bacteria are the predominant fermentative microflora. In all three assays, this flora reached 5.10^9 cfu/g after 24 h of fermentation (Figure 5).

In the natural cassava fermentation, within the first 24 h, a simultaneous production of lactic and acetic acids and traces of propionic and butyric acids and ethanol were observed. But, although the acetate content reached its maximum level (10 g/kg DM) and remained constant after the first day of fermentation, the lactate concentration began increasing from the second day of the process. This suggests that fermentation is primarily related to

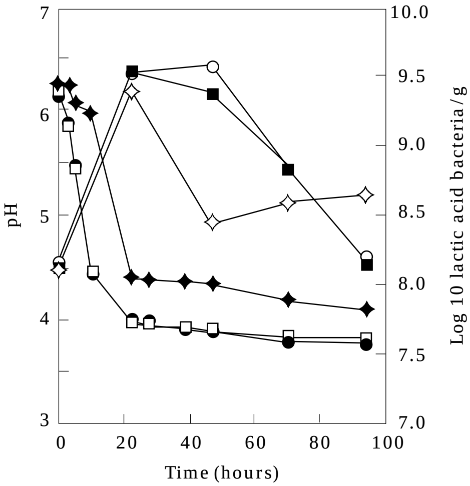

Figure 5. Changes in pH and numbers of lactic acid bacteria (l.a.b.) during cassava fermentation. (✦ = pH and ✧ = l.a.b. in natural fermentation; ● = pH and ○ = l.a.b. in fermentation inoculated with *Lactobacillus plantarum* A6; □ = pH and ■ = l.a.b. in fermentation inoculated with *L. plantarum* Lacto Labo.)

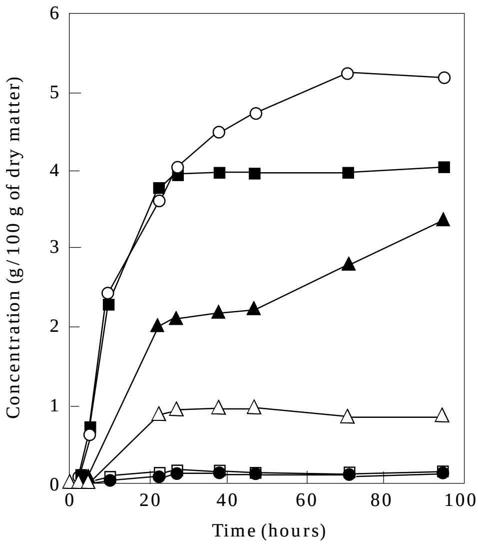

Figure 6. Evolution of lactate and acetate concentration during cassava fermentation. (▲ = lactate and △ = acetate in natural fermentation; ○ = lactate and ● = acetate in fermentation inoculated with *Lactobacillus plantarum* A6; ■ = lactate and □ = acetate in fermentation inoculated with *L. plantarum* Lacto Labo.)

an heterolactic flora growth, which is supplanted by a more acid-tolerant homolactic flora.

This hypothesis is supported by Oyewole and Odunfa (1990), who studied the characteristics and distribution of lactic acid microflora during the preparation of *fufu*. They reported a predominant development of *Leuconostoc mesenteroides*, which was subsequently replaced by *L. plantarum*. They suggested that this sequence resulted because *L. mesenteroides* was unable to tolerate increasing acidity.

In the inoculated fermentations, the lactic acid content was higher. The production kinetics of this acid were identical in both *L. plantarum* strains during the first 24 h. But, on the second day, this concentration reached its maximum (40 g/kg DM) and remained constant in the control strain. In contrast, in the amylolytic strain (*L. plantarum* A6), lactate production continued to rise, increasing by 25%.

Traces of ethanol, propionate, and butyrate were also found in the inoculated fermentation assays. Furthermore, the lower acetate production showed that a massive inoculation with an *L. plantarum* strain inhibited the development of the natural heterolactic microflora.

Conclusions

The presence of amylase in lactic acid bacteria has already been reported. But, as far as we know, no author has described any amylolytic strain of *L. plantarum*. When investigating the bacterial microflora of fermented cassava roots, Regez et al. (1988) isolated numerous *L. plantarum* strains, but did not report any amylolytic strains. Scheirlinck et al. (1989) studied the integration of the α-amylase gene of *Bacillus stearothermophilus* in the genome of an *L. plantarum* strain, but did not verify the expression, stability, and competitiveness of the transformed strain in a natural medium.

In our research, we had isolated a natural amylolytic strain of *L. plantarum* from cassava roots. Our data, as reported here, suggest that this new lactic acid bacterium is of particular interest, not only for its taxonomy, but also for its capacity to develop rapidly and massively in starch-based media.

Finally, preliminary trials of inoculating cassava with *L. plantarum* A6 for *gari* production demonstrate that this strain may play a significant role in developing organoleptic qualities, and in standardizing and preserving the final product because of the large amounts of lactic acid produced and the resulting faster and significant drop in pH values.

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CHAPTER 25

CASSAVA WASTES: THEIR CHARACTERIZATION, AND USES AND TREATMENT IN BRAZIL[1]

*M. P. Cereda** and *M. Takahashi***

Introduction

Cassava is widely grown in Brazil. It is used fresh, that is, directly, in cooking; processed into a typical flour, known as *farinha*; and for starch extraction. All the resulting food products have no or nontoxic levels of cyanide (Table 1). Most cyanide is carried away by the wastes, whether liquid or solid.

The crop is grown in diverse production systems, ranging from small farms to plantations. Depending on their quantity and composition, cassava residues can damage the environment and even constitute profit losses. Culinary use, for example, does not produce significant amounts of residues. In contrast, industrial use may cause environmental problems. Even tiny factories such as the *casas de farinha* can produce significant quantities of residues, because of their tendency to cluster in certain areas or cities. For example, sour or fermented-starch factories are concentrated by the hundreds in two districts of Minas Gerais State: Divinópolis and Pouso Alegre. Paranaví, a district of Paraná State, has a concentration of about 150 flour factories of different sizes.

Cassava Structure and Composition

The literature on cassava's structure and chemical composition is variable. Nevertheless, the data overall suggest that the cassava root is caloric, and generates about 1,500 cal/kg from about 350 g/kg of carbohydrates. The average values of other components are about 50 g/kg. Phosphorus and calcium contents are higher. Iron may occur, but in low quantities. Hegarty and Wadsworth (1968) state that raw cassava usually has an iron content of 1 to 2 mg/100 g of dry matter, but warn that if the analytical equipment used is made of iron, then such content may reach as high as 3.2 mg/100 g.

Table 2 shows the differences in composition when cassava leaves are considered. Oke (1968) details cassava root composition, mainly as mineral contents, as follows:

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1. No abstract was provided by the authors.

Humidity: 71.50%

Dry matter (g/100 g):
- crude protein = 2.60
- crude fiber = 0.43
- ash = 2.40
- lipids = 0.46
- carbohydrates = 94.10

Ash minerals (g/kg):
- nitrogen = 0.84
- potassium = 1.38
- phosphorus = 0.15
- calcium = 0.13

Other minerals (mg/kg):
- sodium = 56.00
- iron = 18.00
- boron = 3.30
- molybdenum = 0.90
- magnesium = 12.00
- copper = 8.40
- zinc = 24.00
- aluminum = 19.00

Other components:
- oxalate = 0.32%
- phytic acid = 76.00%
- HCN = 38.00 mg/100 g

The potassium content is greater than that of calcium, phosphorus, and iron. The idea that cultivating cassava weakens the soil is probably based on this fact.

Group B vitamins occur in cassava varieties with yellow pulp. These varieties are normally used by factories only in the northern states of Brazil. Cassava roots have high vitamin C content, but it can be destroyed in factory processing or cooking.

The literature differs on the nitrogen fraction of cassava roots. The traditional methodology evaluates proteins by multiplying crude nitrogen by a factor. Cereal or other, vegetable, factors are calculated in this way. Oke (1968) does not consider this accurate enough because a factor for cassava amino acids has yet to be established. Despite being low, cassava proteins are overestimated because root nitrogen fractions include both a proteinic fraction and nonproteinic compounds. The nitrogen of the linamarin radical (CN), for example, could be wrongly considered as part of the protein evaluation of raw cassava or cassava fractions.

Sreeramamurthy (1945) reports that the traditional solvents of protein methodology fail to extract some nitrogen, part of which is of a proteinic nature. For example, copper hydroxide separates and precipitates only 10% of total protein. The cassava proteinic fraction contains arginine, tryptophan, and cystine, and important amino acids. Cassava root protein is small in quantity rather than low in quality when compared with casein, egg albumin, and the protein fractions of cabbage and sweetpotatoes. In contrast, Rogers (1965) suggests that cassava protein is low in histidine, proline, glycine, and amino acids containing sulfur (e.g.,

Table 1. Composition (in percentage) of some typical cassava products, Brazil. Numbers are rounded.

Component	Product			
	Farinha flour	Starch	Sour starch	Chips
Humidity	1.2	1.1	1.6	0.9
Dry matter:				
Carbohydrates	93.0	97.3	95.6	94.0
Proteins	1.3	0.6	1.5	1.7
Lipids	0.1	0.3	0.3	0.3
Crude fiber	3.3	0.6	0.7	1.1
Ash	1.1	0.1	0.3	0.4
Cyanide	0	0	0	1.6

SOURCE: Faculdade de Ciências Agronômicas (FCA), Universidade Estadual Paulista (UNESP), unpublished data.

Table 2. Central American cassava cultivars: root and leaf composition. Numbers are rounded.

Component	Root size			Leaves
	Long, thin	Medium	Short, thick	
Humidity (%)	62.10	61.10	62.10	77.20
Dry matter (g/100 g):				
Fiber	1.60	1.25	1.14	2.54
Lipids	0.65	0.20	0.24	1.31
Nitrogen	0.32	0.17	0.11	1.10
Carbohydrates	32.95	34.18	34.70	10.33
Ash	1.20	1.20	0.86	1.77
Other components (mg/kg):				
Calcium	46.00	27.00	27.00	206.00
Phosphorus	78.00	66.00	43.00	95.00
Iron	1.60	0.50	0.50	3.50
Carotene	0.01	0.01	0.01	4.53
Thiamine	0.09	0.06	0.05	0.15
Riboflavin	0.04	0.04	0.30	0.30
Niacin	0.82	0.72	0.60	2.02
Ascorbic acid	32.00	40.75	41.40	211.00

SOURCE: Calculated from Martelli, 1951.

methionine, cystine, threonine, isoleucine, and tryptophan).

Cassava juice is milky, smells of cyanide, and consists of 91.00% water, 0.13% essential oils containing sulfur, 2.30% gum, 1.14% saponins, 1.66% glycosides, and 3.80% nonspecified components.

Oke (1968) reported cassava lipids from 0.1% to 1.0%, made up of 35% palmitic, 3% stearic, 39% oleic, 18% linoleic, and 5% linolenic acids.

The literature rarely mentions cassava fiber. Despite cassava roots being fibrous, the processing method that uses acid and alkaline hydrolysis yields only about 2.0% fiber, whereas other methods (such as neutral detergent analysis or enzymatic analysis) yield almost 20%.

Carbohydrate is the highest fraction of cassava root composition, with starch constituting the largest part. Oke (1968) puts the nonstarchy fraction of the carbohydrates at 3.5%, of which 1.79% is composed of reducing sugars (0.93% glucose, 0.43% fructose, and 0.43% maltose) and 1.71% nonreducing sugars (1.70% saccharose and 0.01% raffinose). Oke considers starch content as being 35% of the fresh matter, and possibly higher if total carbohydrates are calculated by difference. Amylase hydrolyzes cassava starch to 48% in its granular or raw form and to 78% when previously boiled.

Sugar originating from starch may increase if fermentation takes place. According to Amido (Um novo caminho..., 1973), fermentation during starch extraction and purification causes loss of starch because it turns into soluble sugars.

Sreeramamurthy (1945) concluded that cassava roots are mainly starchy. They contain less than 1% protein, have a very low lipid content, and are poor in minerals and group B vitamins, although fresh roots have considerable vitamin C content.

Toxic Cassava Glycosides

Cooke (1979) describes both lotaustralin and linamarin, the toxic glycosides found in the cassava plant (Table 3), as being able to generate hydrocyanic acid. Although free cyanide is well known to be toxic, the toxicity of glycocyanide is still unknown.

Oke (1969) reported that linamarin is a β-glucoside of acetone cyanohydrin, and lotaustralin of ethyl-methyl-ketone-cyanohydrin. The more representative glucoside is linamarin, which constitutes 80% of total glucosides. He also suggested that glucosides in linked form are not toxic to the plants themselves.

Oke hypothesized that the glucosides are intermediate compounds in protein synthesis, such as from amino acids that are constituted from the nitrate absorbed by roots. Thus, the cyanogenic glucosides are stable intermediates that do not accumulate if conditions for protein synthesis are favorable. Glucoside synthesis probably starts with glycine.

The toxic action of cyanide (released when cell walls are damaged) on animals is explained by the cyanide's affinity to iron, combining with hemoglobin to form cyanohemoglobin. In higher plants and microorganisms (Cereda et al., 1981), cyanide interferes with the oxidative phosphorylation pathway, combining with cytochrome-oxidase to inhibit electronic transportation and thus the formation of adenosine triphosphate (ATP).

Table 3. Cyanogen glycoside concentration (mg/kg of tissue) in cassava tissues of sweet and bitter cultivars (*Manihot esculenta* Crantz).

Cultivars	Seeds	10-day-old plantlets	Mature leaves	Roots
Sweet	0	285.0	468.0	125.0
Bitter	7.5	245.0	310.0	185.0

SOURCE: Nartey, 1981.

For animals, calculating the quantity sufficient to cause death (lethal dose) is done by experiment and expressed in mg per kilo of live weight. Oke (1969) mentions that 1 mg/kg of live weight is considered the limit for humans, and is used to classify cassava roots into poisonous or nonpoisonous, according to the amount of cyanogenic potential in the root. The literature mentions values ranging from 15 to 400 mg of hydrocyanic acid per kg of fresh cassava roots, although average values are 30 to 150 ppm (Carvalho and Carvalho, 1979).

Oke (1969) suggests that, in processed foods made from cassava, the hydrolytic enzyme of the plant linamarase remains active and catalyzes a reaction that releases molecules of glucose, acetone, and hydrocyanic acid in proportions of 1:1:1. Linamarase has an optimal pH of 5.5 to 6.0. Glucose can act as an antidote because it changes the reaction's direction and cooperates with glucoside synthesis.

Microorganisms consume free glucose in preference to glucoside. Coop and Blakey (1948), cited by Oke (1969), confirmed this hypothesis. When an extract of cassava in a solution containing 1 to 3 ppm of HCl with a pH of 6.5, was placed in the presence of 2% glucose, the released cyanide content did not change. Nor was the extract toxic when incubated with rumen liquid. Determining the pH is important, because reaction rate depends on it. Animals, in general, have a detoxification mechanism that can prevent death when reaction is slow. It operates in swine, whose stomachs are monogastric, with a pH of 3.0, but does not effectively prevent death in bovines, which have polygastric stomachs, with a pH of 7.0.

Microorganisms can develop on substrates that contain cyanide if they have an anaerobic metabolism—an alternative mechanism to the respiratory chain (Cereda et al., 1981)—or if they can detoxify cyanide by splitting the radical into carbon and nitrogen (Jensen and Abdel-Ghaffar, 1969). This fact may explain the related fertilizing effect of waste-water spillage from cassava processing.

Cassava Wastes

Cassava wastes are plant residues generated by processing. Waste quality and quantity vary greatly because of such factors as plant age, time after harvesting, kind of industrial equipment, and its adjustment.

In Brazil, cassava roots are mostly processed into flour (which generates more solid residues) and starch (more liquid residues). Some solid wastes are brown peel, inner peel, unusable roots, crude bran, bran, bagasse, and flour refuse. Among the liquid wastes is *manipueira*, which is formed during flour making by pressing bulk quantities of cassava roots. It is also formed during starch extraction, but the water used in the process dilutes the *manipueira*, reducing its organic load and cyanide content, but vastly increasing its output. Water from washing roots is also considered as liquid waste. Figures 1 to 5 show the relationships between cassava

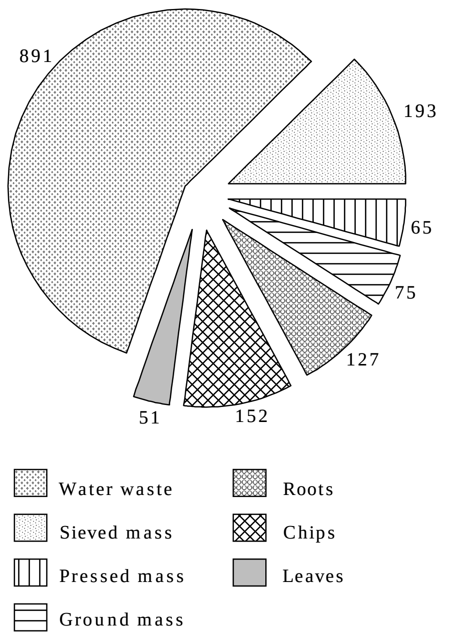

Figure 1. Cyanide content (ppm of HCN) of plant parts, products, and wastes of processing cassava cultivar IAC 12 829.

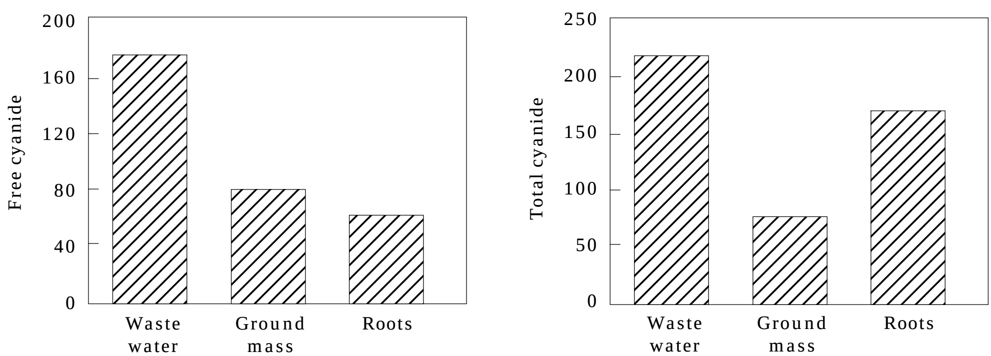

Figure 2. Free and total cyanogens (ppm of HCN) in products of a cassava flour factory (Equipamento Zaccharias), using cassava cultivar IAC 12 829 at 24 months old, São Paulo, Brazil.

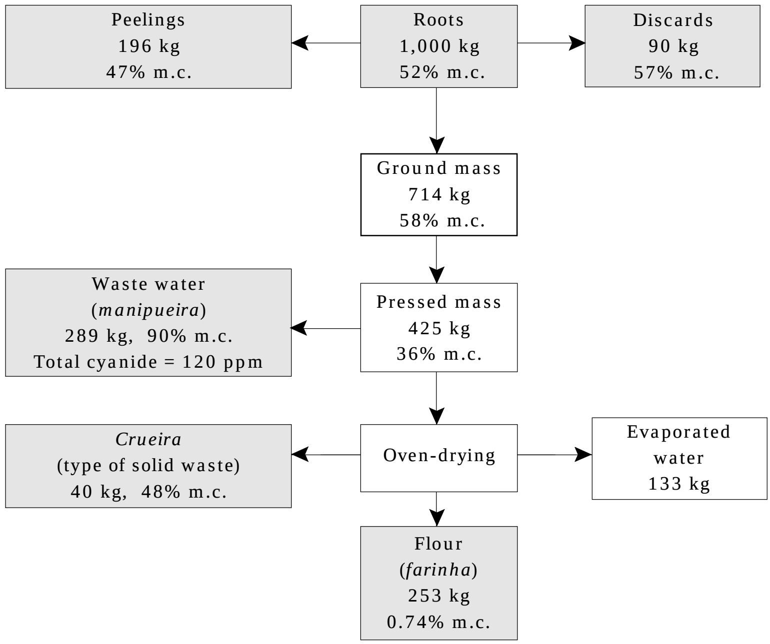

Figure 3. Mass balance of a fermented-starch factory, Colombia. (m.c. = moisture content.) (After Arguedas and Cooke, 1982.)

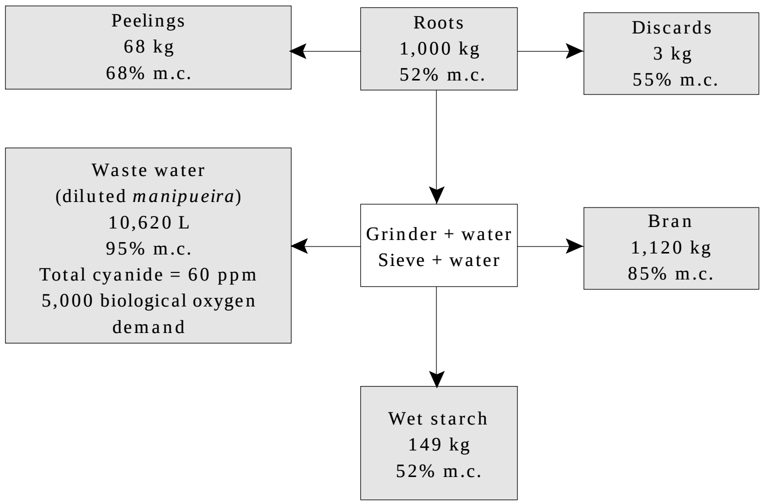

Figure 4. Mass balance of a fermented-starch factory, which used cassava variety Branca de Santa Catarina at 24 months old, Minas Gerais State, Brazil. (m.c. = moisture content.)

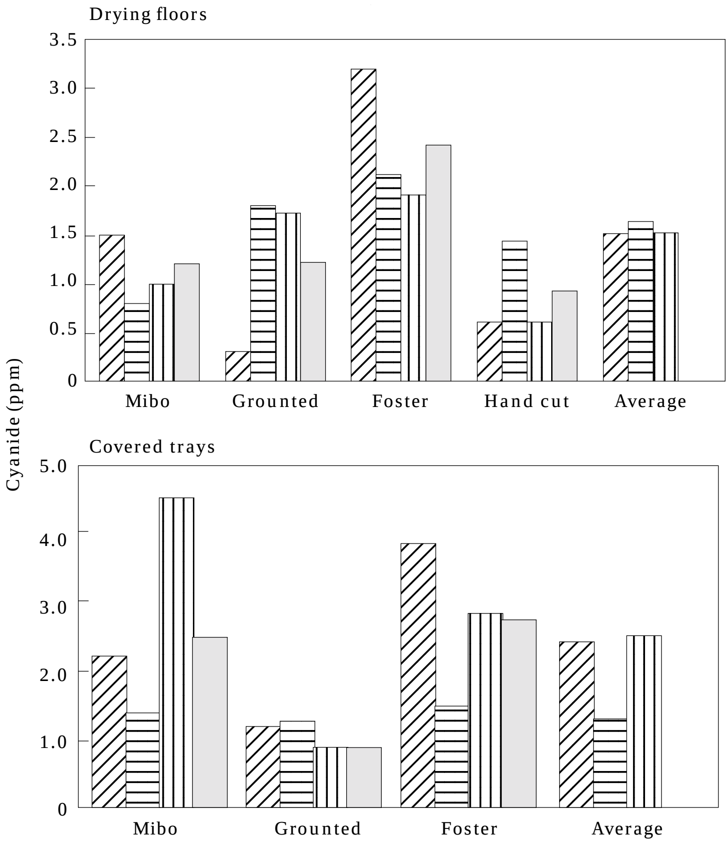

Figure 5. Cyanide reduction in cassava chips processed at three factories and by hand cutting, Brazil. (= 5 kg/m² = 10 kg/m² = 15 kg/m² = Average.)

processing, cultivars, and wastes in the material balance of cassava flour and sour starch production.

Solid wastes

Peelings. The brown peel, sometimes called bark, of cassava roots corresponds, in technical terms, to the periderm and varies between 2% and 5% of the root total. It is thin and cellulosic, and although usually dark brown, can be white or cream-colored. A small quantity of inner peel, or cortical parenchyma, may come off with the bark, causing losses in starch factories. In *farinha* factories, if the inner peel is highly fibrous, it is best taken off. In industrial terms, peelings are residues and refer to the mixture of both inner peel and bark. Table 4 shows the average composition of several samples of peelings. Peelings can be used as fertilizer or animal feed.

Discards. These are produced during selection, so as not to overwork the rasper. Their composition is similar to that of cassava roots but is more fibrous because they contain the peduncle. Moisture content is 55%-60%. The

Table 4. Chemical composition of cassava peelings. Average values of several samples are given. Dashes indicate that no data were available.

Component	Peelings		
	Outer (bark)	Inner	Mixture
Humidity (%)	48.3	65.6	72.3
Dry matter:			
Volatile solids (%)	-	-	26.2
Ash (%)	4.0	3.0	1.4
Soluble carbohydrates (%)	-	-	7.9
Starch (%)	0	58.0	32.0
Lipids (%)	3.0	2.0	0.6
Nitrogen (%)	0.6	1.3	2.1
Fiber (%)	41.0	6.0	-
Lignin (% SV)	-	-	6.5
Free cyanide (ppm)	-	-	23.9
Total cyanide (ppm)	0	320.0	120.0
Phosphorus (ppm)	60.0	-	60.0
Potassium (ppm)	430.0	-	430.0
Calcium (ppm)	280.0	-	280.0
Magnesium (ppm)	80.0	-	80.0
Iron (ppm)	5,538.0	-	26.0
Copper (ppm)	9.0	-	9.0
Zinc (ppm)	21.0	-	21.0
Manganese (ppm)	104.0	-	103.0
Sulfur (ppm)	110.0	-	320.0
Boron (ppm)	18.0	-	18.0
Volatile acidity (mg acetic acid/L)	-	-	5,548.0
Alkalinity (mg bicarbonate/L)	-	-	2,191.0
C/N ratio	-	-	6.4
C/P ratio	-	-	0.3

SOURCE: Motta, 1985.

quality of discards depends on the cultivar and on root age. Together with bran, discards may be used raw as animal feed, thus bringing extra income for the industry. The values shown in Figures 3 and 4 may be overestimated, because the process is still being investigated.

Bran or bagasse. This solid waste is made up of fibrous root material, and contains starch that physically could not be extracted. It is produced as starch is separated. It has a large absorption capacity and may contain about 75% moisture. Table 5 shows the chemical composition of bran after partial drying, with differences according to the technology used. Table 6 shows the composition of sun-dried bran from fermented-starch factories in Minas Gerais, Brazil.

Crude bran. Another type of solid waste is crude bran (*farinhão* or *crueira*), which is made up of pieces of root and inner peel. In cassava-flour processing (at Equipamento Zaccharias, São Paulo State), these are separated out by sieving before being oven-dried. Table 7 (p. 231) shows the composition of such waste. At other factories (e.g., Mádia, Paraná State), these residues are replaced by fine threads (*fiapos*) made up of cassava fibers. Another solid residue is cassava-flour refuse, the grated mass that daily falls and collects on the floor.

Table 5. Differences in chemical composition of bran according to technology adopted. Dashes indicate that no data were available.

Component[a]	Type of technology		
	Royal[b]	Minas[c]	*Fiapos*[b]
Humidity (%)	9.42	14.82	9.52
Dry matter:			
Ash (%)	0.83	3.77	0.66
Soluble carbohydrates (%)	0.01	-	-
Starch (%)	69.76	74.99	63.85
Lipids (%)	0.65	0.28	0.83
Nitrogen (%)	0.24	1.86	0.32
Fiber (%)	11.08	7.81	14.88
Total cyanide (ppm)	0	0	-
Phosphorus (ppm)	-	30.00	-
Potassium (ppm)	-	280.00	-
Calcium (ppm)	-	90.00	-
pH	4.00	-	-

a. No data were available for the following components: volatile solids, lignin, free cyanide, magnesium, iron, copper, zinc, manganese, sulfur, boron, volatile acidity, alkalinity, C/N and C/P ratios, chemical oxygen demand, or titratable acid.

b. Large factory.

c. Small, traditional factory.

Table 6. Average composition of sun-dried bran from 20 fermented-starch factories (traditional) from Pouso Alegre and Divinópolis, Minais Gerais, Brazil.

Component	Average values (%)[a]	
	Pouso Alegre	Divinópolis
Starch	63.6	2.78
Soluble carbohydrates[b]	0.2	0.10
Protein	2.3	0.34
Phosphorus	0	0.01
Calcium	0.1	0.03
Potassium	0.3	0.06
Lipids	0.6	0.35
Fiber	8.3	2.06

a. Numbers are rounded.

b. Expressed in percentage of glucose.

SOURCE: Escola Superior de Agricultura de Lavras (ESAL), unpublished data.

Liquid wastes

Lagoon mud. Table 7 also shows the composition of sedimented lagoon mud and liquid wastes. Sometimes these are sun-dried and used as fertilizer. The use of thin starch is also uncommon.

Manipueira. Diluted *manipueira* is a liquid waste from cassava starch extraction and sour-starch manufacture. It may be waste water from root washing, after the washer/husker has removed soil and peelings and the water is decanted or filtered. The average factory volume is 2.62 m^3. Waste water may also be extracted from pressed and grated cake in flour manufacturing and from the roots themselves. It is also a byproduct of starch extraction (average factory volume is 3.68 m^3).

The average composition of *manipueira* sampled from different starch factories in São Paulo State is variable, as shown in the following list (numbers are rounded):

Component	Value
Humidity (%)	93.7
Dry matter (g %):	
Total solids	6.3
Volatile solids	5.2
Starch	0
Soluble carbohydrates	0.5
Lipids	0.5
Ash	1.1
Crude nitrogen	0.5
Fiber	0.3
Lignin	6.0
Free cyanide	43.7
Total cyanide	444.0
Dry matter (ppm):	
Phosphorus	160.8
Potassium	1,863.5
Calcium	227.5
Magnesium	405.0
Iron	15.3
Copper	1.1
Zinc	4.2
Manganese	3.7
Sulfur	19.5
Boron	5.0
Chemical oxygen demand	6,365.5
Volatile acidity (mg acetic acid/L)	2,703.7
Alkalinity (mg bicarbonate/L)	1,628.0
C/N ratio	7.6
C/P ratio	34.4
Titratable acidity (ml NaOH N%)	3.3
pH	4.1

Cyanogen content tends to be high, but varies according to cultivar. The organic load is also high, and varies with the type of processing used (Table 8). All residual starch is removed from *manipueira* before treatment. It has most soluble and some insoluble substances in suspension and this residue carries almost all the cyanogenic glycosides existing in the disintegrated root mass.

The water used in starch factories carries high concentrations of these glycosides (linamarin and lotaustralin) (Sobrinho, 1975). They are hydrolyzed by linamarase enzyme and acid, making the cyanide a free radicle (CN) (Williams, 1979).

According to Sobrinho (1975), liquid waste thrown onto soil or into waterways causes pollution. If the pollution rate of starch factories is expressed as biological oxygen demand (BOD) over 5 days, at 20 °C, and calculated as 24 g per habitant per day, it would be equivalent to that caused by 150-250 habitants per day—very high. In Santa Catarina State, the pollution caused by these wastes corresponds to 460 habitants per day (Anrain, 1983).

Conclusions

Cassava wastes can be used in different ways. The solid residues can be used as animal feed; the literature shows that cassava waste can replace a part or all of the feed components. *Manipueira* can be used in agriculture as a herbicide, nematicide, insecticide, or fertilizer. Anaerobic digestion is well studied in Brazil and is more advantageous than aerobic digestion. *Manipueira* comes from flour industries, and the best processing method uses the separated phases reactor. We now need to study how to optimize the acidic phase.

Cassava waste can also be used for biomass production. The yeast *Trichosporon* sp. can be isolated by natural fermentation with a cyanide-resistant respiration pathway, and potentially can produce both a proteinic and a fat biomass.

Table 7. Chemical composition of different types of cassava wastes, averaged over several analyses. Numbers are rounded. Dashes indicate no data were available.

Component[a]	Type of waste		
	Farinhão[b]	*Varredura*[c]	Lagoon mud
Humidity (%)	11.7	-	4.9
Dry matter (g %):			
Soluble carbohydrates	1.1	-	61.4
Lipids	68.5	-	1.8
Nitrogen	1.7	-	0.1
Fiber	0.5	0.5	1.8
Lignin (% SV)	-	-	9.7
Dry matter (ppm):			
Free cyanide	-	-	0
Total cyanide	-	-	0
Phosphorus	70.0	70.0	540.0
Potassium	700.0	640.0	240.0
Calcium	130.0	90.0	140.0
Magnesium	60.0	50.0	60.0
Iron	41.0	32.0	23,800.0
Copper	2.0	3.0	63.0
Zinc	8.0	8.0	75.0
Manganese	20.0	18.0	105.0
Sulfur	30.0	30.0	46.0
Boron	20.0	7.0	14.0
pH	5.4	-	5.4
Titratable acidity (ml NaOH N %)	3.7	-	3.9

a. No data were available for volatile solids, ash, and starch.

b. *Farinhão* = solid waste made of pieces of cassava roots and inner peels.

c. *Editor's note:* No explanation of this term was provided by the authors.

Table 8. Composition of extraction water (mg/L) from the Fleischmann-Royal factory, Conchal, São Paulo State, Brazil.

Component	Range measured
Chemical oxygen demand	6,280-51,200
Biological oxygen demand	1,400-34,300
Total solids	5,800-56,460
Soluble solids	4,900-20,460
Suspended solids	950-16,000
Fixed solids	1,800-20,460
Organic matter	1,500-30,000
Reducing sugars	2,800-8,200
Total phosphate	155-598
Total nitrogen	140-1,150
Ash	350-800
Sedimentable solids (1 h)	11-33
Cyanide content	22.0-27.1
pH	3.8-5.2

SOURCE: Lamo and Menezes, 1979.

The microorganisms can also be used to produce such biomasses as organic acids (citric or lactic), biological insecticides, and enzymes.

Solid wastes also have a potential use for foodstuffs. The production of high-fiber biscuits from bagasse is being studied at the Faculdade de Ciências Agronômicas (FCA) of the Universidade Estadual Paulista (UNESP).

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Chapter 26

Cassava Starch Extraction: A Typical Rural Agroindustry with a High Contamination Potential

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Abstract

Every year, about 5,500 t of starch are produced in Colombia from about 27,000 t of cassava roots. Starch production usually involves simple technology, consuming an average of 23 m^3 of water per ton of cassava. This generates a contaminating load of about 180 kg of chemical oxygen demand (COD) per ton of roots. An average of 13.5 t of COD is discharged into Colombian rivers each day.

Processing generates two liquid residues: the first results from the washing and peeling of cassava roots, and generally contains a large amount of inert material with low COD; the second results from draining the starch sedimentation tank, and has a high contaminating load of COD and biochemical oxygen demand (BOD).

A pilot project was proposed to treat waste waters, using an anaerobic filter and a transfilter. The transfilter technology has been tested in France, yielding good results with household effluents. Its operating principle is based on immobilizing microorganisms on a lignocellulose support. The hydrodynamic characteristics of three types of supports—sugarcane bagasse, bamboo, and *paja de monte* (underbrush straw)—were determined in the laboratory. *Paja de monte* showed the best characteristics.

These studies will be complemented with the monitoring of existing microflora as changes occur in operational parameters.

Introduction

Agroindustrial processes generate large volumes of waste waters and solid residues whose quality varies according to the process used. Generally, farm activities use abundant water to wash and treat products, at which point the water is loaded with harmful elements and compounds. These are directly discharged into rivers and streams, representing a risk for the environment, and the reduced quality makes the water less suitable for other uses.

Colombia is a mainly agricultural country, with small and medium-sized agroindustries widely scattered. This makes conventional water treatment

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systems onerous to use, given the small volumes of products processed. But versatile water treatment systems are now available at low cost and are attractive alternatives within the reach of small industries.

The feasibility of applying transfilter systems (anaerobic processing) to purify these discharges is being studied by the Universidad del Valle (UV), Cali, Colombia, in collaboration with the Institut français de recherche scientifique pour le développement en coopération (ORSTOM), France, and is financially supported by the European Union (EU). A pilot reactor will be located in a starch factory in the Cauca Department. The Corporación Autónoma Regional del Valle del Cauca (CVC) will build a pilot anaerobic filter at the same site, so both can be evaluated from technical and economic viewpoints.

Waste Waters from Cassava Starch Extraction

Production and identification of waste waters

About 200 cassava-starch production factories are located in the Cauca Department, most in the north. Their annual consumption of cassava roots is about 27,000 t, from which they extract about 5,500 t of starch. Plant processing capacity ranges from 500 to 2,500 kg fresh roots per day (Janssen and De Jong, 1981).

Cassava-starch extraction involves several stages: root washing and peeling, rasping, screening, starch sedimentation, and, for sour starch, fermentation (Figure 1). Roots are washed in a tank or drum. They can also be peeled in a drum, but this operation removes only 60% to 70% of the peel, the remainder being peeled

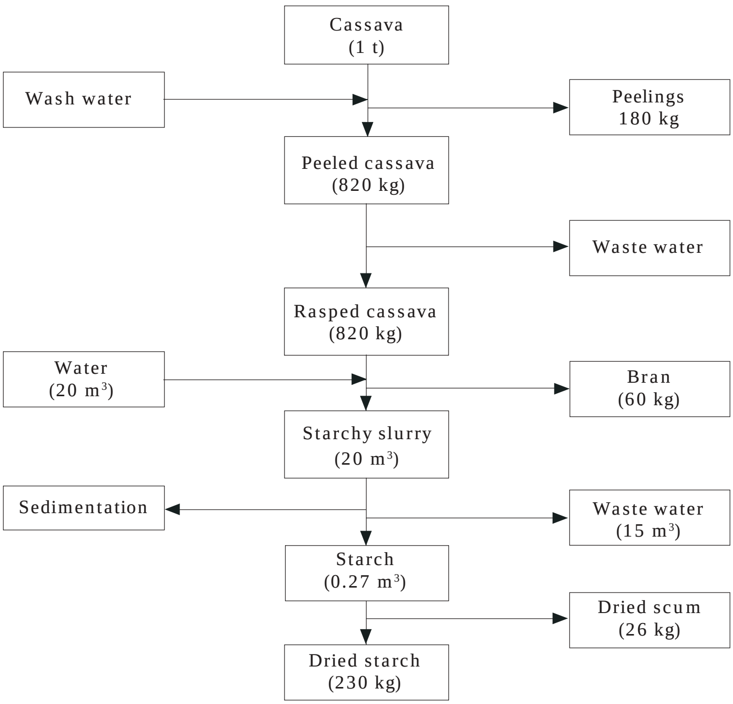

Figure 1. Characterization of waste water from cassava starch extraction.

by hand. This first stage of washing and peeling generates the first waste waters.

The roots are rasped, and the pulp sieved through a nylon mesh that covers the inside of the screening drum. The starchy slurry is left to settle for 20 to 24 h in sedimentation tanks, until the starch layer is 25 to 30 cm thick. The liquid is drained and discarded, and the extracted starch passes to fermentation tanks, which are completely filled and then covered with a thin layer of water. Fermentation takes about 4 weeks (Pinto, 1978).

Use of solid residues

When water is separated from starch in the sedimentation tank, a layer of greyish material is formed over the starch, called *mancha* by starch manufacturers. This film, or proteinaceous fraction, can be easily removed and dried. It is frequently used as animal feed and is widely accepted in the market.

Characteristics of waste waters

Waste water results from two processing stages: the washing of peeled cassava and the draining of the sedimentation tanks (Figure 1). The former contains a large amount of inert material and has a low COD, and the latter, high organic loads of BOD and COD.

Analyses of waste water samples taken from sedimentation tanks at different starch factories were carried out by the UV and the CVC. Average values were obtained to indicate the approximate composition of such water. According to this information, the volume of waste water discharged per processing plant per day ranges from 18 to 48 m^3. The average overall contaminant load is about 13.5 t of COD per day, or 3.45 t of BOD per day.

The use of anaerobic digestion to purify waste waters from cassava starch extraction

The results of characterizing the drainage water from sedimentation tanks permitted an analysis of the possibility of applying anaerobic treatment to this type of residue. The average COD value (900 mg/L) is high compared with that of BOD (300 mg/L), suggesting a high COD-to-BOD ratio and the presence of a high COD content, resistant to biological degradation. But the UV and CVC's preliminary research indicates that this factor is less important in terms of anaerobic biodegradation. When specifically tested to determine the percentage of organic matter biologically degradable under anaerobic conditions, the percentage of biodegradability was found to be 83%.

The results of waste water analyses show that a sufficient amount of nitrogen, a major element in biomass growth, is present in the residues. But the amount of phosphorus, another essential macronutrient, is deficient (Table 1).

The pH of drainage water from the sedimentation tank ranges from 3.9 to 4.7, which means the residue must be neutralized before being fed to the reactor.

The low cyanide concentration in the waste water (average 2.12 mg/L) suggests that the microbial biomass can adapt to this inhibitor. Methanogenic bacteria first react by reducing methane (CH_4) production, but, within a few days, they adapt to the cyanide and finally decompose it.

Based on this finding, the UV and the CVC conducted studies to see if anaerobic processes are applicable for treating this type of discharge (Table 2). Additional studies are now being conducted on a pilot scale.

Table 1. Characteristics of waste waters resulting from cassava starch extraction (average values).

Parameter	Average value	Range[a]
COD[b] (mg O_2/L)	9,100	4,000 - 12,800
BOD[c] (mg O_2/L)	3,100	1,500 - 8,600
COD/BOD (ratio)	2.9	-
Cyanides (mg CN^-/L)	2.12	1.2 - 4.04
Total solids (mg/L)	5,740	2,680 - 10,020
Volatile solids (mg/L)	4,870	2,020 - 9,320
Total organic carbon	2,420	870 - 5,300
pH (units)	-	3.9 - 4.7
Temperature (°C)	-	19 - 22
Sedimentation (ml/L)	29	15 - 47
Nitrogen (mg.N/L)	105	29 - 233
Phosphorus (mg.P/L)	2.34	0.3 - 6.0

a. This range is broad due to the amount of material processed.
b. COD = Chemical oxygen demand.
c. BOD = Biochemical oxygen demand.

SOURCE: Raddatz, 1986.

Table 2. Results of laboratory and pilot studies on the feasibility of anaerobic treatment of waste water from cassava processing, carried out by the Universidad del Valle and the Corporación Autónoma Regional del Valle del Cauca, Colombia.

Description[a]	12-liter reactor			23-liter reactor[b]		
	n	Average	∂n-1	n	Average	∂n-1
Effluent flow (ml/min)[c]	52	16.8	6.40	14	10.8	4.6
COD_{Af} (mg/L)[c]	52	3,294	2,732	14	1,640	1,263
COD_{Ef} (mg/L)[c]	52	659	56	12	105	26
OVL (kg COD/m^3.day)[c]	52	5.02	2.46	12	4.31	3.2
Removal COD (%)[c]	36	95	2	12	85.4	12.1
Biogas production (L/day)	53	16.4	8.4	-	-	-

a. COD_{Af} = chemical oxygen demand in affluent flow; COD_{Ef} = chemical oxygen demand in effluent flow; OVL = organic volume load.
b. The effluent was recycled by about 30%.
c. These units refer to average values of the COD.

SOURCES: Escandón, 1988; Hernández, 1987.

Methanogenic activity in mud was measured in the 12-liter reactor, increasing significantly from an initial rate of 0.063 kg COD-CH_4/kg VSS (volatile suspended solids) to a rate of 0.188 kg COD-CH_4/kg VSS. Although cyanide concentration was measured only a few times, it was calculated as decreasing by about 69%.

Transfiltering

This is a type of anaerobic treatment, using a lignocellulose base to filter particulate material present in the waste water, and to fix those microorganisms responsible for biodecomposing waste organic matter. The support bed decomposes with time so it has to be changed regularly; this also prevents silting.

Three operations occur simultaneously within the transfilter: (1) waste waters are purified by filtration and the organic material present in the waste is digested; (2) biogas (an energy resource) is produced; and (3) the lignocellulose material (a solid waste appropriate for compost) is digested. Figure 2 is a diagram of a transfilter reactor (Farinet, 1993).

The UV is conducting laboratory research on the transfilter process based on waste waters from cassava starch extraction. A pilot reactor will later be built at a starch factory in the Cauca Department.

So far, with sugarcane bagasse, *paja de monte*, and bamboo as support beds, the following hydrodynamic characteristics were determined: volume of waste water eliminated from the supports, and load loss from clean water flowing through the filtering medium, as affected by water velocity and density of medium (compression).

Results showed very low load losses for higher velocities (35 m/h), and for stronger compressions (120 kg/m^3 for bagasse and 100 kg/m^3 for *paja de monte*). Maximum load loss was 7 cm for bagasse 1 m long and 6.3 cm for *paja de monte*. No load loss was observed in bamboo (Gotin, 1993). Technically, any of these materials can therefore be used, if due attention is paid to the operating criteria.

To complement the research on types of support, further studies on the filtration capacity of *paja de monte* will be made at a pilot starch factory. The aim is to determine the maximum compression of the support at which optimal filtration efficiency is obtained for a given volume and period in relation to time of silting the filter. The supernatant effluent from the starch sedimentation tanks will be the waste water treated.

To define constraints to designing the pilot reactor, feasibility studies on methanizing the filter effluent will be conducted in the laboratory, based on previous results.

Bacterial microflora will also be studied for their composition, distribution, and nature of the different groups of bacteria involved

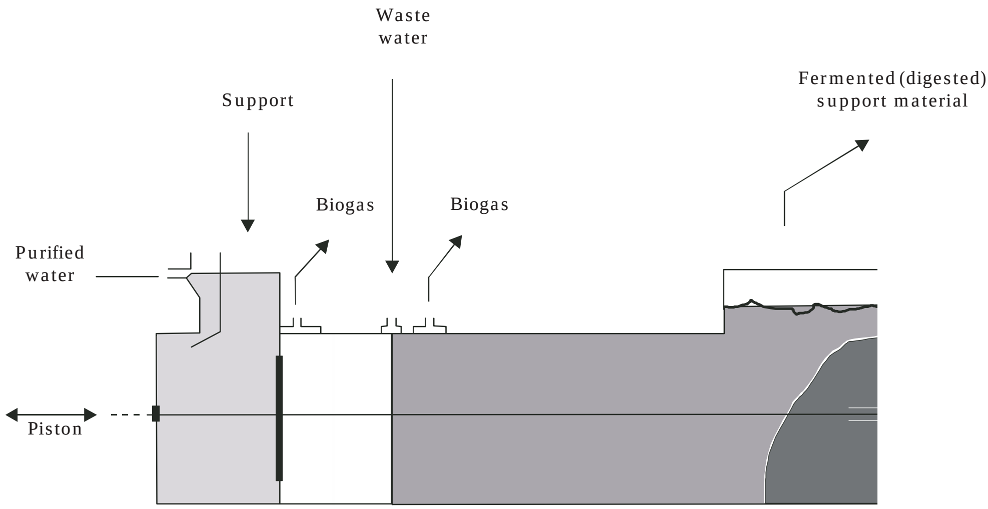

Figure 2. A transfilter reactor, used for the anaerobic treatment of waste water from cassava starch extraction. (From Farinet, 1993.)

and their interactions. Considerable knowledge is already available on the metabolic pathways of the microbiological process of anaerobic fermentation (hydrolysis, acidogenesis, acetogenesis, and methanogenesis).

We will quantify and characterize the active bacterial microflora responsible for biodegrading the effluent at each stage of the process. The evolution, and the density, of each group of bacteria will also be assessed throughout the operation of the digestor.

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Session 5:

Technology Development

CHAPTER 27

IMPROVING CASSAVA SOUR STARCH QUALITY IN COLOMBIA[1]

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Introduction

Fermented or "sour" starch extracted from cassava is used in Colombia to prepare traditional, gluten-free, cheese breads such as *pandeyuca* and *pandebono.* Starch extraction consists of peeling, washing, and grating fresh cassava roots. The pulp is then screened under running water to obtain starch milk or *lechada*. The starch is then sedimented out and placed into wooden or tiled tanks (about 1 m^3), where it ferments naturally over 20 to 30 days under anaerobic conditions and at an average temperature of 21 °C. The resulting sour starch is then sun-dried to obtain a stable product with 10%-15% moisture, and is marketed (Brabet and Dufour, 1996; Jory, 1989).

Bread-making potential (BMP) is the main criterion of quality for sour starch and is defined as the ability of the starch to swell during baking (Laurent, 1992).

Although quality and rapidity are two major issues in cassava starch production, sour starch is still produced according to traditional methods. Hence, sour starch is highly variable in product quality, limiting its use in food industries.

Fermentation and sun-drying critically influence the BMP of sour starch (Brabet and Dufour, 1996; Larsonneur, 1993). Developing adequate control of and suitable practices for these two processing steps would help stabilize and improve sour starch's economic value and strengthen the status of this agroindustry.

Cassava processors sometimes improve sour starch quality by inoculating batches with surface water from fermentation tanks in which good quality products have been produced. But this practice still results in irregular quality of sour starch.

We therefore studied the natural fermentation of cassava starch in detail, in an attempt to relate the nature of microflora and their effect

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1. No abstract was provided by the authors.

on final product quality. We then carried out a cassava starch inoculation trial, using amylolytic lactic acid bacteria (ALAB), isolated and selected from previous fermentation kinetic studies. Our purpose was to standardize product quality and reduce fermentation time.

We also carried out studies to confirm the role of sun-drying in the acquisition of BMP, and to determine the key factors responsible. The trials involved sun-drying kinetic studies, oven-drying at 40 °C and at 55 °C, drying under cover, oven-drying at 40 °C under ultraviolet (UV) light, and drying with water added.

Cassava Starch Fermentation

Natural fermentation

Natural fermentation of cassava starch is characterized by the presence of a predominantly lactic acid flora (10^8-10^9 cfu/g dry matter of starch), confirmed by the rapid and drastic decrease of pH (7 to 3.5 in 5 days), while total acidity increases because of a mainly lactic acid production (Brabet and Dufour, 1996). Lactic acid flora has an active catabolism but its level is constant during fermentation.

At the start of fermentation, starch is the main source of fermentable sugar. Gómez (1993) isolated 75 lactic acid bacterial strains, exhibiting good amylolytic activity, from natural cassava starch fermentation. This ALAB strain bank is currently being molecularly and biochemically characterized.

Previous works have shown modifications of cassava starch physicochemical and rheological characteristics during fermentation (Brabet and Dufour, 1996; Brabet and Mestres, 1991; Camargo et al., 1988; Cárdenas and de Buckle, 1980; Larsonneur, 1993; Nakamura and Park, 1975).

Effect of a starter culture on cassava starch fermentation and quality

A fermentation with starch inoculation was carried out at the "SDT Agroindustrial," a starch-processing plant in La Agustina, Cauca Department, Colombia, using cassava variety CM 523-7. An amylolytic lactic acid bacterial strain, ALAB 20, used for the starch inoculation trial, was isolated from a previous natural cassava starch fermentation and identified as *Lactobacillus crispatus*, using the Gómez (1993) API 50CH system. Flores (1993) studied the physiological parameters of this ALAB 20 strain during a lactic acid fermentation on an MRS-starch medium in a bioreactor. (The glucose in the medium was replaced by soluble starch.)

The fermentation tank was partitioned into two: one part for natural fermentation and the other for inoculated-starch fermentation. Inoculated and noninoculated *lechadas* (aqueous starch suspensions) were first sampled. Then, samples of inoculated and noninoculated starch were taken at 1, 2, 3, 4, 5, 7, 10, 14, and 20 days of fermentation.

Changes in amylolytic and total lactic acid flora. Total lactic acid flora on MRS medium showed no significant difference between inoculated and noninoculated starch (Figures 1 and 2). This flora reached 10^8-10^9 cfu/g of dry matter of starch on the second day and remained constant until the end of fermentation. In contrast, as a proportion of total flora, amylolytic flora on MRS-starch medium (MRS medium where glucose was replaced by 20 g/L of soluble starch) were in a higher proportion in inoculated starch than in noninoculated (Figures 1, 2, and 3). Furthermore, flora were heterogenous during the natural fermentation, whereas the inoculated fermentation resulted in a predominance of the ALAB 20 strain.

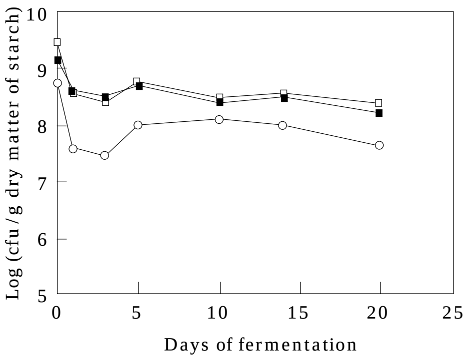

Figure 1. Changes in anaerobic microflora on MRS and MRS-starch media in natural fermentation. (□ = total lactic acid flora on MRS agar; ■ = total flora on MRS-starch agar; ○ = amylolytic flora on MRS-starch agar.)

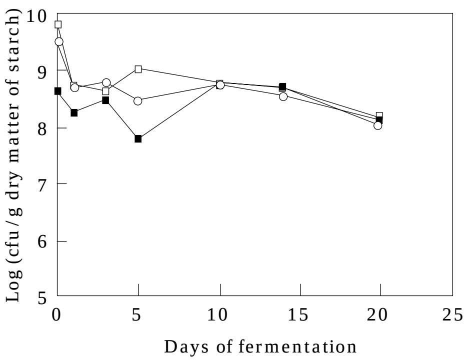

Figure 2. Changes in anaerobic microflora on MRS and MRS-starch media in inoculated-starch fermentation. (□ = total lactic acid flora on MRS agar; ○ = total flora on MRS-starch agar; ■ = amylolytic flora on MRS-starch agar.)

pH and lactic acid production. In the inoculated-starch fermentation, acidification was more notable during the first 5 days of fermentation, but pH value finally stabilized at 3.5 (pK_a of lactic acid) in both fermentations (Figure 4). The inoculated fermentation produced slightly more lactic acid (Figure 5) during the first days of fermentation.

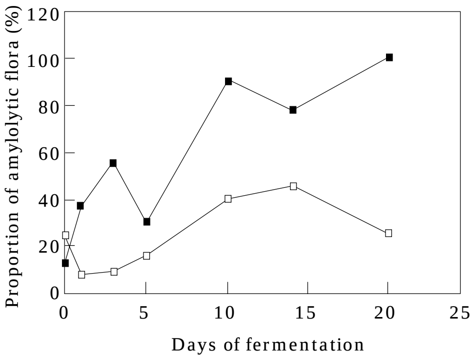

Figure 3. Evolution of amylolytic flora as proportion of total flora on MRS-starch medium during cassava starch fermentation. (□ = natural fermentation; ■ = inoculated-starch fermentation.)

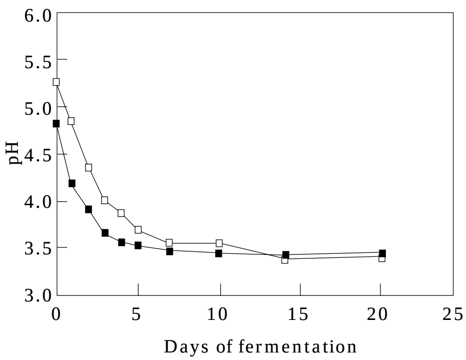

Figure 4. Evolution of pH during cassava starch fermentation. (□ = natural fermentation; ■ = inoculated-starch fermentation.)

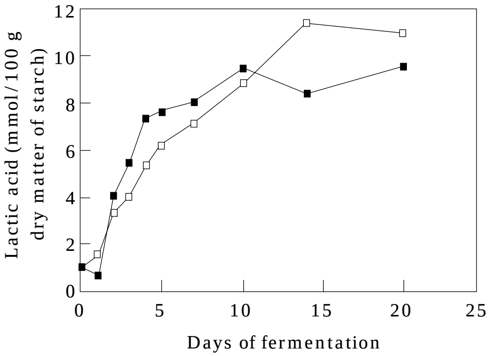

Figure 5. Evolution of lactic acid content during cassava starch fermentation. (□ = natural fermentation; ■ = inoculated-starch fermentation.)

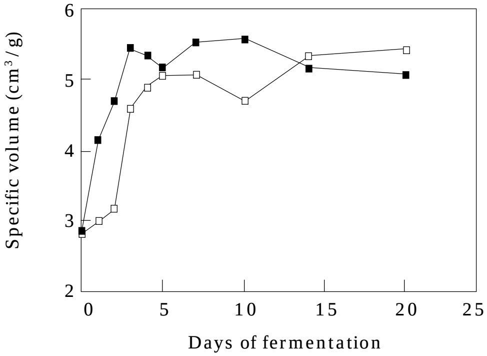

Figure 6. Evolution of cassava starch bread-making capacity during fermentation. (□ = natural fermentation; ■ = inoculated-starch fermentation.)

Bread-making potential of starch. Inoculation of cassava starch with ALAB 20 allowed the final BMP to be reached 10 days earlier, compared with natural fermentation. But the final BMP of the starch was not improved (Figure 6).

Sun-Drying Cassava Sour Starch

Importance of ultraviolet radiation

Kinetic studies of drying cassava sour starch in the sun (8 h) were realized. Sour starch specific BMP increased from 2 cm^3/g (wet starch) to at least 5 cm^3/g in 4 h of sun-drying (Larsonneur, 1993). The same starch sample, when oven-dried at 40 °C (slow drying) or 55 °C (rapid drying), or dried under cover for 8 h, did not expand (specific BMP of 2-2.5 cm^3/g).

These results demonstrate the need for sun-drying if sour starch is to acquire BMP, and the importance of solar radiation. The results also explain why Brazilian plants producing cassava sour starch do not artificially dry starch during the rainy season but ferment it instead for various months until the dry season arrives.

Oven-drying trials of sour cassava starch at 40 °C and under a UV lamp (Cole-Palmer, G-09817-20, 4 W, 254 nm and 366 nm) were conducted for 8 and 16 days. Under UV radiation, the sour starch's capacity for bread making increased to a value close to that of the sun-dried starch control, whereas oven-dried samples expanded little:

Treatment	**Bread-making potential (cm^3/g) at:**		
	8 h	**8 days**	**16 days**
Sun-drying	6.82	6.82	
Oven-drying at 40 °C		2.46	3.18
Oven-drying at 40 °C and under UV:			
254 nm		3.94	4.95
366 nm		3.78	4.75

These results show that UV radiation is one of the different types of sun radiation able to develop the BMP of cassava sour starch. Compared with 8 h of sun-drying, the lengthy period (8 and 16 days) needed to increase the bread-making capacity of sour starch may be explained by the low power (4 W) of the UV lamp used.

The role of water in sun-drying sour starch

Water content of cassava sour starch during sun-drying plays an important role in improving the starch's bread-making capacity. For example, cassava sour starch oven-dried at 40 °C for 8 h, then rehumidified to 50% and sun-dried for another 8 h, had a higher bread-making capacity (5.10 cm^3/g) than the same starch sample dried under the same conditions but without the additional water (3.75 cm^3/g).

Better results are obtained (7.4 cm^3/g) if sour starch is sun-dried at 40 °C for 8 h, then sun-dried for another 8 h, but with water added every hour for 3 h. In contrast, the expansion of the starch in the sun-dried control (8 h) was 5.03 cm^3/g.

Conclusions

To improve the quality of cassava sour starch, the following recommendations should be made to the *rallanderos* (cassava sour starch producers):

(1) *To ferment.* Starch should be fermented for at least 20 days. The pH should be controlled at 3.5. The fermentation tank should be covered with about 5 cm of water to ensure anaerobic conditions and lactic acid fermentation.
(2) *To dry.* Sour starch should be dried under sunny conditions. Starch samples should be turned over to ensure exposure of all starch granules.

The preliminary results of starch inoculation trial demonstrated that the use of ALAB 20 as a starter culture helped reduce fermentation time. Replicated starch inoculation trials, using the same strain, will be undertaken to confirm these results. Other lactic inocula will also be investigated for reducing fermentation time and improving cassava sour starch quality.

From the results cited above, the concept of an artificial drying apparatus, using UV radiation and controlling starch moisture, can be visualized. This would make standardizing sour starch drying and quality possible, which would no longer be at the mercy of the weather.

Studies are being conducted to evaluate the influence of cassava variety and root storage on sour starch quality. Climatic conditions and the water used during production may also have effects.

Acknowledgments

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CHAPTER 28

INVESTIGATING SOUR STARCH PRODUCTION IN BRAZIL

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Abstract

In sour starch producing countries such as Brazil and Colombia, most production is from small and medium-sized plants. If the sector is to develop, it must adapt to changing circumstances, environmental factors, and market demand for improved product quality. Data on current processing operations are essential for identifying and prioritizing development and modernization needs.

This paper presents the results of a detailed, in-depth investigation of sour starch production in southern Brazil. We first describe the major processing operations: root preparation, disintegration, screening for fiber removal, sedimentation, and drying. Then we discuss the inputs and outputs for each operation, the composition of products and intermediates within the process, and, in particular, the volume and composition of waste waters—a factor of increasing environmental concern.

The data are then related to starch production technology used in other countries. Areas identified for future development and improvement include quality definition and standardization, marketing and promotion, and pollution abatement measures.

Introduction

Production of sour starch

In Brazil, sour starch (*polvilho azedo*) is manufactured principally in the State of Minas Gerais (MG), with additional production in São Paulo and Paraná States. Plants are typically small to medium-sized, processing about 10-20 t/day of roots, although larger plants can process as many as 50 t/day.

An estimated 80 plants operate in the municipalities of Cachoeira da Minas and Conceição dos Ouros, in the region of Pouso Alegre, southern MG. Typical plants produce about 3 t/day of starch, although some larger plants produce 10-15 t/day. The Empresa de Assistência Técnica e Extensão Rural (EMATER) (personal communication, 1993) suggests that the region produced about 18,000 t in 1986, and is now producing 12-13 thousand tons per year.

Sour starch production is also concentrated around Divinópolis

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where about 10 small plants operate, each employing three to four people and producing more than 100 t of starch per year (EMATER, personal communication, 1993). These exist alongside more than 100 very small starch production units, based on family farms, which sell to the local market, supermarkets, bakeries, and households. The total 1985 production in the Divinópolis region was estimated to be about 10,000 t. Current production is probably below this figure if trends mirror those of the Pouso Alegre region. No apparent change has occurred in the number of the region's plants during the last 3 years.

Sour starch is used in certain snacks, mainly *pão de quiejo* and *biscoitos*, on sale in public eating places such as cafés and bus stations. The market for these products is stagnating, because of increasing competition from other snack products and the effects of the current economic climate on consumer spending. However, *pão de quiejo* has recently begun to be marketed through a fast-food chain which specializes in the product, and supermarkets have begun stocking it as a frozen product.

Although this expanded market has resulted in a more buoyant demand for sour starch, it has not had the kind of effect on the industry that might have been expected. In Paraná State, especially, producers of *pão de quiejo* are increasingly replacing sour starch with industrially produced, unfermented, sweet starch (*fecula*), or sun-dried sweet starch (*polvilho doce*).

If the local sour starch industry is to survive, it must adapt to changing circumstances—e.g., increased demand for an improved quality product, increasing costs of inputs, and concern for environmental conservation—by improving its processing methods. Before changes can be made, accurate and detailed data are needed on current processing operations. Cereda and Takahashi (Ch. 25, this volume) have gathered information on processing operations in *farinha* and native starch industries in Brazil. But comprehensive data are unavailable on operations and problems experienced in small and medium-sized sour starch plants. We, therefore, conducted a detailed analysis of plant operations in two plants in Minas Gerais.

Production Technology

The small- to medium-scale production of sour starch in Brazil is schematically similar to that of sour starch in Colombia as described by Salazar de Buckle et al. (1971) (Figure 1).

Lorry loads of fresh roots are delivered to the plant and fed into a rotary washer fitted with overhead water sprays for part of its length. As well as washing off dirt and debris, the tumbling action of the roots as they pass along the washer also removes most of the bark. Washed roots are transferred to the hopper-fed, root disintegrator, via an inspection conveyor, at which an operator cuts up excessively large roots, and removes remaining bark and stems.

All plants employ similarly constructed disintegrators known as the "Jahn rasper" (Grace, 1977; Radley 1976). This machine consists of a hollow, cylindrical drum, with tooth-edged steel blades sandwiched between local hardwood slats fixed longitudinally to its surface. The drum is mounted between two circular steel endplates on a central shaft and housed inside a steel casing, the base of which includes a screening plate.

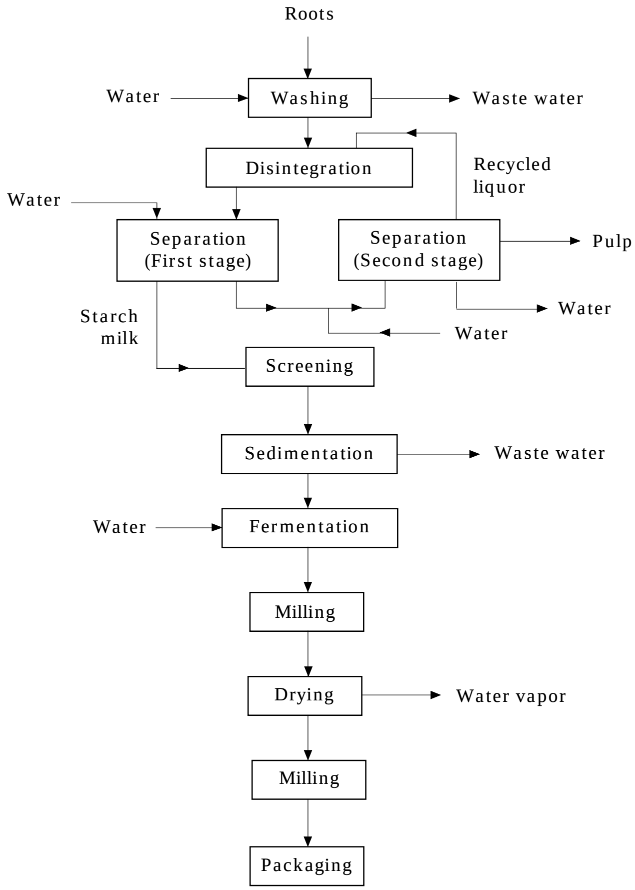

Figure 1. Sour starch manufacture in a typical plant in Minas Gerais State, Brazil.

Recycled liquor from the starch separators is continuously fed into the disintegrator. The resultant slurry of crushed roots passes through the screening plate into a sump tank from which it is pumped to the separators.

All plants employ a two-stage separation process to remove the liberated starch from the fibrous pulp (*massa*). The majority of plants employ two centrifugal separators, which have replaced the traditional, rotating brush-and-screen washers.

The centrifugal separator consists of a rotating conical screen, housed inside a shaped, mild-steel casing, tapering from front to back. The conical screen is a metal frame covered with a nylon mesh. The narrow end of the cone is closed with a fixed metal plate connected to the drive shaft. Slurry is pumped into the center of the separator (toward the fixed plate) and forced through the screen to an outlet at the bottom of the casing into a sump tank. Water is sprayed into the slurry from jets positioned around the screen.

In the sump tank, the slurry receives extra water to facilitate pumping it over a flatbed reciprocating screen to remove any remaining fiber (larger plants employ an additional centrifugal separator). The slurry then enters a second separator for further starch extraction. Liquor discharged from the second separator is returned to the disintegrator, and the suspension of pulp, or "starch milk," is discharged to storage tanks.

The milk then flows into sedimentation channels or "tables" (Bruinsma et al., 1981). Dimensions for the channels vary considerably from plant to plant: in length, from 150 to 200 m; in width, from 0.6 to 1.0 m; and in depth, from 0.4 to 0.6 m. The channels are usually lined with ceramic tiles because both starch and starch milk attack concrete. The channels are roofed to protect the starch from rain or sunlight.

The milk is directed into one end of the channels and the supernatant liquor flows over a weir at the other end to be discharged as waste water into nearby watercourses, seepage pits, or infiltration channels.

After overnight settling, supernatant remaining in the sedimentation channels is discharged by removing the weir. The surface of the settled starch is sometimes washed to remove those uppermost layers containing high concentrations of dirt, protein, and fiber impurities. Over several days, the channels are allowed to fill with successive layers of starch until space is available in the fermentation tanks. The starch is then dug out of the channel, transferred to the tanks, covered with water, and left to ferment for a minimum of 30 days. The tanks are also lined with ceramic tiles and are usually constructed in series adjacent to the sedimentation channels. They, too, are roofed to prevent exposure to sunlight and rain.

After fermentation, the starch is removed from the tanks, broken up with a spike mill, and dried on hessian sacks laid on raised, drying tables, usually made of bamboo. The drying starch is agitated manually at regular intervals. When dry, the starch is collected, milled to a powder, and packaged into 50-kg bags or, in some plants, into packs for direct sale to retailers.

Monitoring Plant Operations

Measuring process parameters and sampling procedures

With the agreement and cooperation of plant management and staff, processing operations at two plants were monitored for 3 weeks. Monitoring activities were:

(1) Measuring water flows within processing operations to determine water consumption at each stage;
(2) Periodic sampling of fresh roots, disintegrator slurry, starch milk, waste fibrous pulp, fermented and dried starch;
(3) Sampling of water supplies and generated effluents throughout the process to characterize pollution loads.

During monitoring, no attempt was made to influence plant management and staff in their work.

Sample analysis

Moisture content of root, starch cake, and pulp samples were determined by oven drying at about 45 °C to constant weight. Dried samples were stored and later analyzed for starch content, using enzyme hydrolysis (AOAC, 1965) and crude fiber (Harris, 1970).

Immediately after collection, the pH of all water and effluent samples was measured with a hand-held meter (CIBA Corning Diagnostics Ltd., Halsted, UK). The samples were then taken to a local laboratory and analyzed for chemical oxygen demand (COD), and suspended and dissolved solids.

Results and Discussion

Root washing

Table 1 shows the proportions of dirt, bark, peel, and parenchyma in the roots received at the two plants and Table 2 shows the composition of the washed roots.

The root washers employed in the two plants had a similar design: a semicircular, slatted trough, 7 m long with a 0.95-m diameter. It had fixed, 4-bladed paddles, mounted 0.3 m apart on an overhead, central rotating shaft, which was driven at 150 rpm by a 2.2-kW (3 HP) motor. In plant A, the trough was fitted with an overhead water spray for the latter two-thirds of its length, whereas in plant B, the spray covered only the last third.

Table 1. Composition (%) of residues from washing fresh cassava roots at two plants producing sour starch, Minas Gerais, Brazil.

Component	Plant A	Plant B
Dirt	0.50	0.49
Bark	2.35	1.84
Peel	15.01	17.47
Parenchyma	82.14	80.20

The flow of roots through the washers was, in effect, the same for both plants at 0.55 kg/s of fresh roots. But plant A used a much larger volume of water for washing: about 1.95 L/s (or 3.55 m^3/t of roots), compared with 0.70 L/s (or 1.27 m^3/t) for plant B (Table 3). The washer's performance at plant A, as measured by the percentage removal of bark, was considerably more effective (about 95%), compared with that of plant B (78% to 80%). At plant B higher levels of dirt and bark fragments were visibly observable in the sedimented starch.

Large sweet-starch plants in Brazil and India employ similar washers. In smaller Brazilian and Colombian plants, root washing is performed in batches, using rotating, slatted drums with a continuous supply of water. But in medium-sized plants in India, roots are passed through a flatbed conveyor washer, removing only the dirt and leaving the bark (Trim et al., 1993). For sago production, both the bark and peel are removed manually.

Table 2. Composition of roots, starch, and pulp at two plants producing sour starch, Minas Gerais, Brazil.

Sample	Component (% DM)[a]					
	Total solids (%)	Starch	Crude fiber	Fat	Protein	Ash
Plant A:						
Washed roots	34.45	89.35	1.92	0.44	2.55	1.32
Dried starch	88.10	96.59	0.35	-	-	-
Pulp	7.70	85.59	8.45	0.16	1.36	0.96
Plant B:						
Washed roots	36.85	90.11	2.16	0.19	2.68	1.10
Dried starch	88.73	96.43	0.41	-	-	-
Pulp	7.23	82.21	12.14	0.24	1.79	1.26

a. (% DM) = percentage of dry matter.

Table 3. Total water consumption at two plants producing sour cassava starch, Minas Gerais, Brazil.

Operation	Water consumption	
	m^3/t of roots	m^3/t of product
Plant A:		
Root washing	3.55	15.24
Starch extraction	3.78	16.22
Total	7.33	31.46
Plant B:		
Root washing	1.27	4.70
Starch extraction	4.50	16.67
Total	5.77	21.37

Root disintegration

The drums in the disintegrators at the two plants were of similar construction, 0.32 m in diameter and 0.28 m in width. The blades were longitudinally spaced, at about 12 mm, around the circumference of the drum. Each drum had 80 to 85 blades. The disintegrators were both directly driven by an electric motor and rotated at 2,500 rpm. However, plant A employed a smaller motor (11.2 kW or 15 HP) than did plant B (18.6 kW or 25 HP). Both plants employed 1.5-kW (2 HP) centrifugal pumps to transfer the slurry from the disintegrator sump to the separators.

The total solids content of the disintegrated root slurry at plant A was 8.2% and at plant B, 7.6%. Although these values are similar, the disintegrator at plant B produced a much finer slurry, indicating a higher degree of root maceration. This was reflected in the starch extraction efficiency (i.e., the fraction of starch released in disintegration) at plant A (81%), compared with plant B (84%). These figures are considerably higher than those quoted by Bruinsma et al. (1981) of 61% to 68% for small- to medium-scale production, but close to that reported by Trim et al. (1993) of 83% for an Indian sago plant. However, in the Indian plant, two perforated drum disintegrators were used in series to improve starch extraction.

The operation of the disintegrator at plant B was much smoother, with less notable strain on the motor, because of variation in feeding the roots. Furthermore, the plant operator thought that the throughput of roots in the disintegrator could be increased, thus increasing maximum output.

Starch separation

Plant A employed two identical centrifugal separators, both belt-driven from a common 3.7-kW (5 HP) motor and rotating at 650 rpm. The rotating conical screen in each was 0.70 m in length, 0.25 m in diameter at the narrow end, and 0.76 m at the wider end. It was covered with nylon mesh (PA-120-125/ASTM[1]). The steel casing was 1 m squared in front, tapering to 0.5 m squared at the back.

Water was fed to the first separator at 0.90 L/s and to the second at 0.72 L/s. Fresh water was also added to the sump tank between the separators at a rate of 0.44 L/s. The total water added was therefore 2.06 L/s (3.78 m^3/t of roots). Starch milk was discharged from the first separator directly into the sedimentation channel at a rate of 1.99 L/s with a concentration of solids at 7.1%.

Plant B used a single centrifugal separator, identical to those at plant A, for the primary stage, and a rotating brush-and-screen washer for

1. ASTM = American Society for Testing and Materials.

the second stage. The operating speed of the centrifugal separator at 760 rpm was higher than at plant A, although using a similarly powered motor.

The brush-and-screen washer consisted of a semicircular, screened trough (5.65 m long and 0.42 m in diameter), above which a shaft, rotating at 530 rpm, was centrally mounted. Plastic brushes were spaced at 90 mm intervals along the shaft, which was rotated by a 2.2-kW (2 HP) centrifugal pump.

Water was sprayed into the separator at a rate of 0.74 L/s and into the washer at 0.55 L/s; 1.20 L/s of water was fed into the sump tank between the two. Total water consumption was therefore 2.48 L/s (4.51 m^3/t of roots). Starch milk was discharged from the washer at a rate of 2.52 L/s with a concentration of solids at 6.80%.

The solids content of the waste pulp was 7.70% in plant A and 7.23% in plant B (Table 2). The starch content of the pulp at plant A was 85.59% and at plant B, 82.21%. The higher concentration from plant A again indicates less efficient disintegration of the roots. Trim et al. (1993) measured a starch concentration of 72% in the pulp discharged from a system of reciprocating screens.

The concentration of free starch in the waste pulp was very low at both plants (0.32% at plant A and 0.18% at plant B), indicating a high efficiency of extraction of free starch from the pulp.

Sedimentation and fermentation

Plant A used six channels, constructed side by side and connected in series to minimize space and ease unloading. Each channel was 32 m long, 0.74 m wide, and 0.4 m deep. Plant B had four similarly constructed channels, each 45 m long, 0.82 m wide, and 0.5 m deep. Both sets of channels had a weir, 0.15 m high, at one end. The residence time for starch milk flowing into empty channels was 3.0 h for plant A and 2.4 h for plant B. The solids content of batches of sedimented starch removed from the channels averaged 59.9% for plant A and 59.1% for plant B.

In India, tanks are used instead of channels for sedimentation, largely because of historical reasons (Trim et al., 1993). After overnight settling and removal of the supernatant liquor, the starch cake had a concentration of solids at 50%, but after washing, the concentration was 55%.

Starch and crude fiber concentrations of the settled cake in the two plants were similar, averaging 96.7% for starch and 0.3% for crude fiber (dry matter basis).

The changes occurring in the starch as a result of fermentation are the subject of much recent research (e.g., Brabet et al., Ch. 27, this volume) but were not studied in this investigation. Although a minimum fermentation time of 30 days is necessary, starch often remained in the tanks at the two plants for longer periods because of the lack of available drying space. Such prolonged fermentation had no detrimental effect on starch quality. The temperature of the fermenting starch at the two plants ranged between 12 and 13 °C.

Drying

Both plants employed traditional drying tables, raised about 1 m from the ground. They were essentially bamboo mats (*esteiras*), 4.0 m long and 1.2 m wide, tied to bamboo beams mounted on wooden stakes. Plant A had 600 *esteiras*, with a total drying area of 2,800 m^2, and plant B had 760 *esteiras* (3,650 m^2). The fermented starch was spread on cotton sacks stretched across the tables with a wet starch loading of about 1.8 to 2.0 kg/m^2.

In summer, drying may take 6 to 7 h, but in winter it may take 2 working days or 13 h. Starch that is still damp by the end of the day is gathered up in cotton sacks and placed in storage sheds overnight.

Figure 2 shows the drying curves for batches of starch dried at the two plants (moisture contents are given on a wet basis). As calculated from Table 2, the moisture content (dry basis) of the dried starch produced at plant A was 11.9% and that at plant B, 11.3%. The dried starch contents were 96.6% at plant A and 96.4% at plant B (dry matter basis) (Table 2).

Many plants in the area are investing in drying tables made of wire mesh within wooden frames. The mesh provides improved ventilation around the starch and so reduces drying time.

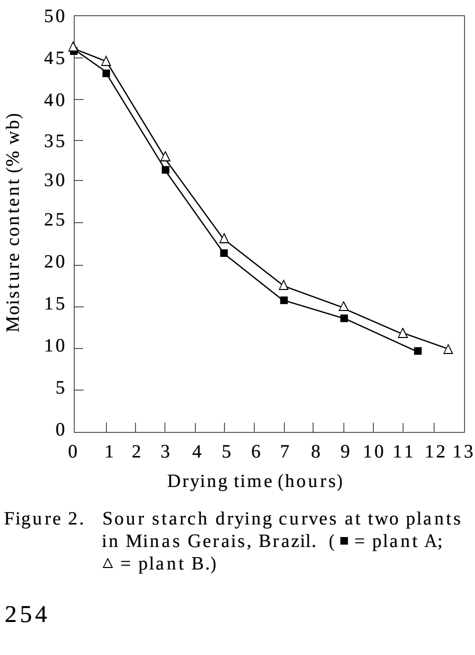

Figure 2. Sour starch drying curves at two plants in Minas Gerais, Brazil. (■ = plant A; △ = plant B.)

Material balance

The material balance for the processing operations at the two plants was calculated from the measured data of process flows and from results of laboratory analyses (Figures 3 and 4). Figure 3 shows that the total mass flow of dried starch in plant A was 23% and Figure 4, 27% in plant B. A more accurate comparison is that of starch recovery efficiency—the fraction of starch in the roots recovered in the product. The overall starch recovery was about 67% for plant A and 72% for plant B.

Product quality

Table 2 gives the composition of the starch products. The results indicate no significant difference in starch purity in products from the two plants, especially in root washing, despite their different processing procedures.

Processors commonly define quality in terms of the degree of whiteness and the acid taste of the sour starch, but no data exist to confirm that these criteria are linked to commercial value. Producers believe quality improves the more the processing environment is clean, the more water used, and the purer the processing water. Spring water is usually preferred to well or river water. The lower temperature of spring water is also believed to improve fermentation. Intense sunlight and agitated air movement around the starch on a second or third day's drying may deteriorate quality by encouraging growth of mold.

Water consumption and characteristics of waste water

Plant A used more water for root washing (3.55 m^3/t of roots) than did plant B (1.27 m^3/t) (Table 3). However, plant A used appreciably less water for root disintegration and starch separation (3.78 m^3/t) than did plant B (4.50 m^3/t). Total water consumption was 7.33 m^3/t for plant A, and 5.77 m^3/t for plant B. The flow of water recycled from the separators to the disintegrator was marginally different in the two plants: plant A recycled 3.50 m^3/t and plant B, 4.22 m^3/t. In sago production in India (Trim et al., 1993), water consumption was 6.40 m^3/t, of which 4.10 m^3/t was used for disintegration and separation.

Table 4 shows the results of analyses of the two principal effluents from the plants. These data confirm the highly polluting nature of these waste waters. The COD of the waste waters from plant A was 4,800 mg/L and from plant B, 3,500 mg/L. The CODs of the supernatant liquor discharged from the sedimentation channels were 11,500 mg/L for plant A and 14,800 mg/L for plant B, that is, much higher than the 6,700 mg/L noted in liquor discharged from sedimentation tanks in India (Trim et al., 1993).

Analyses also indicated that the supernatant liquors contained significant levels of cyanide

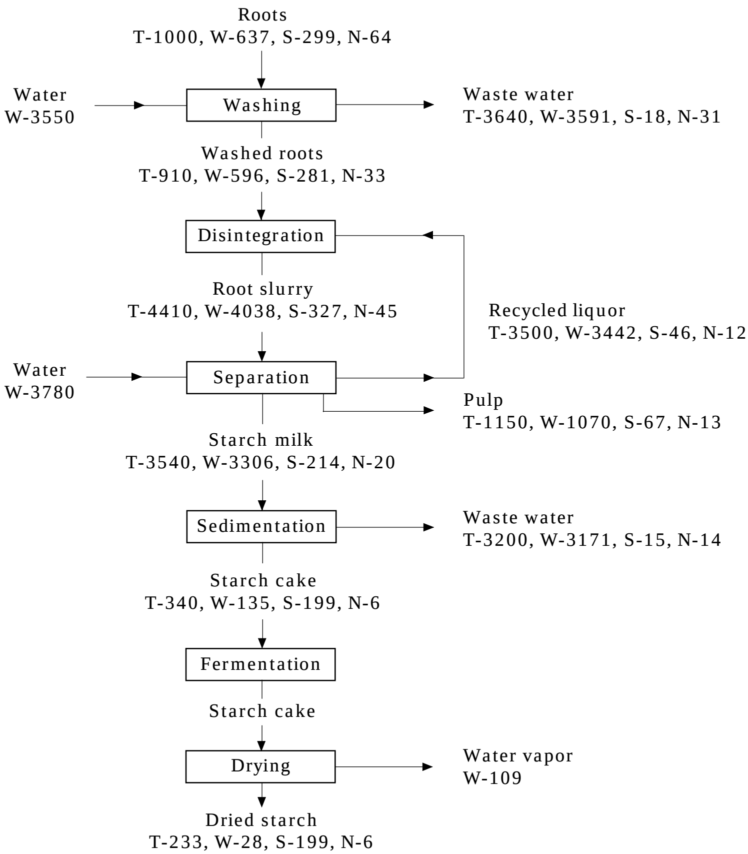

Figure 3. Material balance, based on 1,000 kg of roots, for plant A in Minas Gerais, Brazil. (T = total mass flow; W = water flow; S = starch flow; N = flow of nonstarch components.)

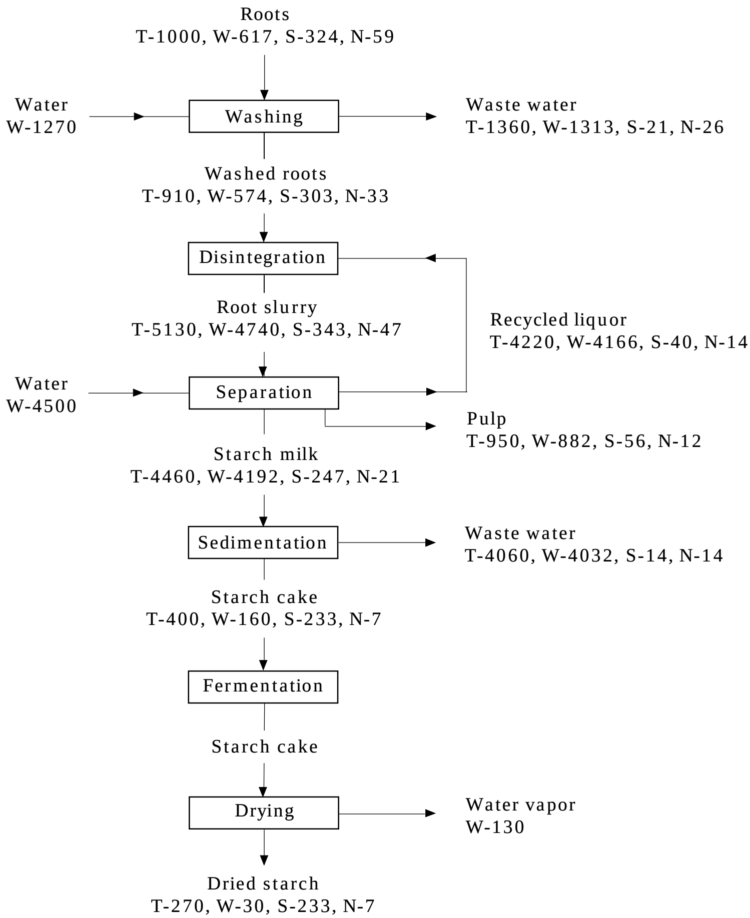

Figure 4. Material balance, based on 1,000 kg of roots for plant B in Minas Gerais, Brazil. (T = total mass flow; W = water flow; S = starch flow; N = flow of nonstarch components.)

Table 4. Characteristics of waste waters at two plants processing cassava sour starch in Minas Gerais, Brazil.

Sample	Characteristic[a]				
	COD (mg/L)	DS (mg/L)	SS (mg/L)	pH	HCN (mg/kg)
Plant A:					
Waste waters	4,778	401	1,297	5.93	
Supernatant liquor	11,538	1,516	7,351	5.11	43
Plant B:					
Waste waters	3,475	618	1,797	6.21	
Supernatant liquor	14,778	3,370	4,979	5.38	62

a. COD = chemical oxygen demand; DS = dissolved solids; SS = suspended solids.

compounds, measured at 43-62 mg/kg. These values are much higher than those measured in India (20-35 mg/kg). The roots used in India for sago production are peeled before disintegration, thus carrying away larger quantities of cyanogens.

Effluent treatment

The effluent problem is a major environmental issue in both Pouso Alegre and Divinópolis. Many plants discharge their effluent directly into small streams feeding the local river. Fish and animals have been killed by polluted watercourses, and the State Water Authority is concerned about the dangers of polluting drinking water supplies.

Federal legislation requires that plants install effluent treatment systems capable of removing at least 85% of the pollution load. Some local authorities have threatened legal action against plants that do not install treatment systems, despite the fact that no effective treatment systems are available that are also economically feasible. In reality, however, plant closures are unlikely because of local socioeconomic factors, and pollution will continue until cost-effective solutions are found.

The most commonly used disposal systems include seepage pits (usually three pits used in series) or infiltration channels, which allow water to seep through the soil. The solid material is removed periodically and used as fertilizer. Some plants use the effluent for irrigating their cassava crop. The long-term effects of these methods are unknown.

Conclusions

The two plants studied, and most of the others visited, were efficiently organized and the equipment usually well maintained. Some significant changes in processing have been adopted over recent years, most notably the introduction of centrifugal separators for the recovery of starch from the macerated roots. An effective means of technology transfer exists through the localized nature of the industry, the local equipment supply and maintenance workshops, and plant workers setting up their own processing plants.

Plant operators see the most important issues as being:

- Availability and price of cassava roots;
- Access to “soft” loans to finance working capital;
- Labor costs;
- Packaging costs;
- Marketing and promotion;
- Perception of improved quality by consumers;
- Efficient and cost-effective effluent treatment systems.

Processors also consider fermentation and drying to be processing bottlenecks. The long fermentation periods tie up scarce working capital, and sun-drying is sometimes unreliable and requires considerable space. But, if improved technology for rapid fermentation and artificial drying become reality, then large-scale industrialists in other areas may be able to undercut small-scale producers in product price by having access to cheaper root supplies and reaching economies of scale. Such undercutting would mean the collapse of a large proportion of the industry in Minas Gerais.

The market for sour starch products is growing slowly, but competition in supply is intensifying and quality is becoming more important. Producers in Minas

Gerais may well encounter future problems as a result of increasing competition from new producers (especially in São Paulo State), who have greater financial resources, access to higher levels of technology, and are located near cheap and abundant supplies of roots.

Future priorities for research should be concentrated in three areas:

(1) *Product quality*. Quality factors need to be clearly defined and standards established. Relationships between process inputs, operations, and quality factors need to be identified and evaluated.
(2) *Markets*. Promotional efforts are required to expand consumer awareness of sour starch and its specialized properties and uses.
(3) *Water pollution*. Affordable technology for water conservation, waste reduction, and treatment operations needs to be developed to minimize pollution.

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CHAPTER 29

IMPLEMENTING TECHNOLOGICAL INNOVATIONS IN CASSAVA FLOUR AND STARCH PROCESSING: A CASE STUDY IN ECUADOR[1]

*Vicente Ruiz**

Background

Before 1985, the only cassava processing technology known in Ecuador was mechanical rasping and hand-sieving to extract starch from the roots. Since then, new technologies have been introduced, and existing ones improved, to increase processing efficiency and open new markets for both cassava starch and flour.

These new technologies include chipping, drying, and grinding cassava roots to produce meal and flour from peeled cassava roots, and sieving coarse-grained flours to produce fine ones. Improved equipment for starch processing include raspers with saws, continuous flow washer-peelers, vibrating screens, and sedimentation channels.

In Manabí, Ecuador, a participatory approach has been used to facilitate the adoption of improved technologies. The first step was to train the technical team of the Unión de Asociaciones de Trabajadores Agrícolas, Productores y Procesadores de Yuca (UATAPPY). This team copied and adapted some prototype equipment and tools on-site in the Association's processing plants. The products—cassava starch and flour—were efficiently produced and entered national and international markets.

Flour Processing

Technology introduced from Colombia

In late 1985, trials showed that cassava meal could be technically and economically produced, using a technology introduced from CIAT, Colombia. The technology consisted of chipping, drying, and grinding dried cassava. Chips, produced by a Thai-type, mechanical, disc chipper, are dried on outdoor concrete floors and then ground in hammer mills.

Technology currently used by UATAPPY

In addition to cassava meal, three other types of flour are produced: white industrial flour, table flour, and sieved whole-grain flour. The technology used to produce these flours differs from that for cassava meal (Table 1). To produce white

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1. No abstract was provided by the author.

Table 1. Comparison of steps in the processing of different cassava flours, once roots are received, using current technology, Manabí, Ecuador.

Process (technique)	Flour			
	Cassava meal[a]	White industrial flour	Table flour	Sieved whole-grain flour
Peeling (manual)		X	X	X
Washing (manual, mechanical)			X	X
Chipping (Thai-type disc chipper)	X	X	X	X
Drying (concrete floors)	X	X		
Drying (trays)			X	X
Milling (hammer mill)	X	X	X	X
Sieving (vibrating or centrifuge screen)			X	X
Packaging (polypropylene)	X	X	X	X

a. Original technology, introduced from Colombia. The other products are produced with more recent technology.

industrial flour, the roots are peeled by hand before being fed to the chipper. The rest of the process is the same as for cassava meal. To produce table flour, the roots are peeled and washed before chipping, and then dried naturally on trays, or artificially. Once the dried chips are ground, the resulting flour is sieved through a vibrating or centrifuge screen. Sieved whole-grain flour is produced by passing the meal through a vibrating screen as for table flour.

Starch Processing

Traditional technology used in Ecuador

Manual starch extraction in Ecuador dates back about 50 years. Traditionally, to extract cassava starch, roots are peeled and washed by hand, grated by hand or mechanically with an engine-driven wooden drum covered with a perforated zinc plate, then sieved by hand. Sedimentation is carried out in wooden or concrete tanks, and the starch dried on concrete floors or on paper (Figure 1).

Technology currently used by UATAPPY

The UATAPPY is currently extracting cassava starch with mechanized technology developed with the technical assistance of CIAT and the Fundación Adelanto Comunitario (FACE), and with the financial support of the Fundación para el Desarrollo Agropecuario (FUNDAGRO). Cassava roots undergo the following procedures: washing and peeling, in either batch or continuous flow, with Brazilian-type washers; mechanical rasping with Brazilian-type saw blades; sieving, both by hand and vibrating screens;

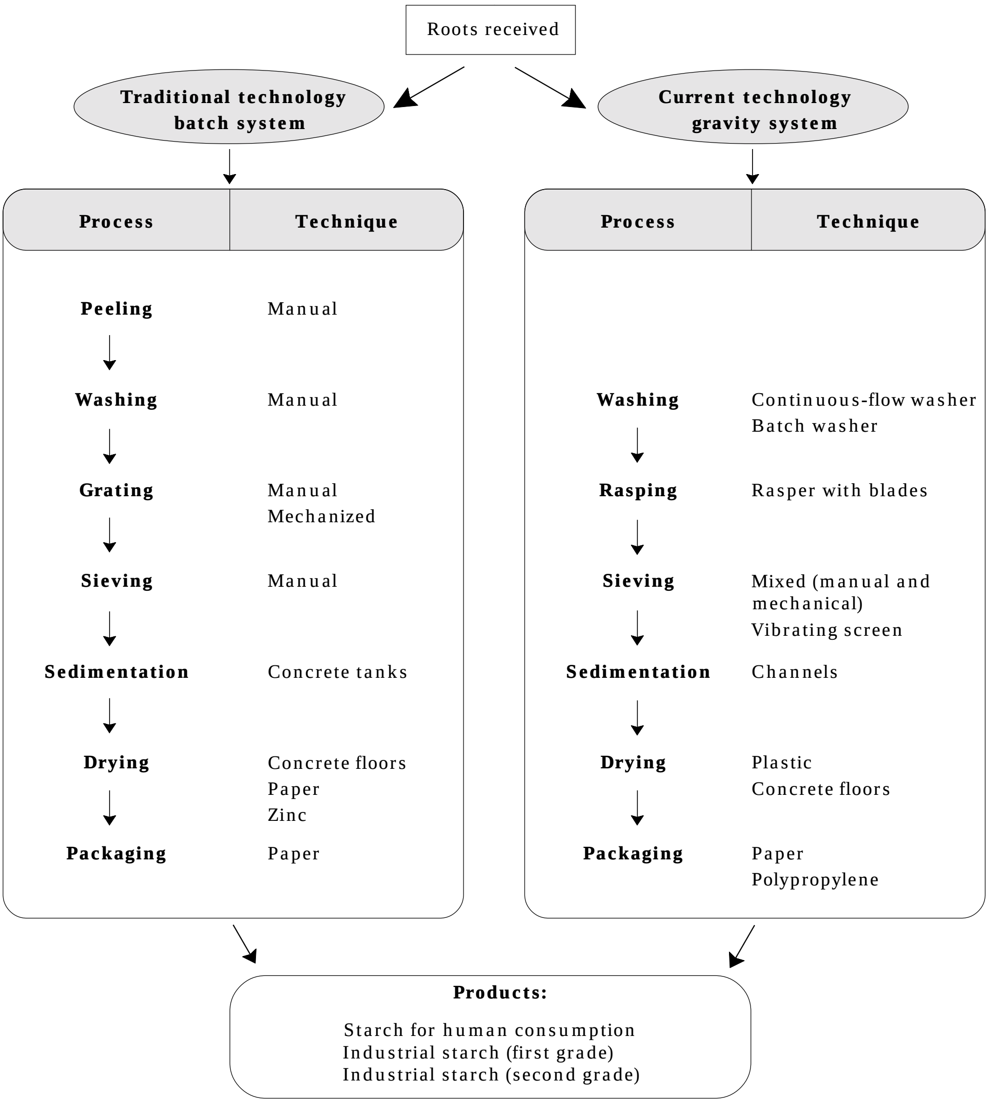

Figure 1. Differences in traditional and current technologies for cassava starch extraction, Manabí, Ecuador. Current technologies include innovations introduced from Colombia and Brazil.

and sedimentation in concrete channels lined with ceramic tiles. Drying is carried out naturally on plastic sheets placed on bamboo platforms. When a finer quality product is required, milling is done in hammer mills (Figure 1).

Experiments

Sour starch production trials were first carried out in December 1992 and renewed in November 1993 at two starch factories, both UATAPPY members. Artificial drying trials with a flash dryer will be conducted, together with mechanized sieving, using vibrating or centrifuge screens.

Training and Institutional Support

To introduce and adapt new cassava processing technologies, especially for starch, UATAPPY received technical and financial support from FUNDAGRO and CIAT. Its technical team has received training nationally and in Colombia and Brazil on elements of processing and technology.

Results

(1) Product quality (flours and starch) has improved, allowing new markets to be opened at national and international levels.
(2) Higher yields have been obtained and efficiency has improved.
(3) Production capacity, especially of starch, has increased.

CHAPTER 30

THE INFLUENCE OF VARIETY AND PROCESSING ON THE PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF CASSAVA STARCH AND FLOUR

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and *C. C. Wheatley*†

Abstract

The influence of certain processing conditions on the quality, functional properties, and product potential of flour made from three cassava cultivars are being evaluated as part of a project (DGXII) funded by the European Union (EU). The collaborators in this project are the Universidad del Valle (UNIVALLE), Colombia; CIRAD-SAR, France; the Natural Resources Institute (NRI), UK; and CIAT, Colombia.

The influence of drying temperature (40, 60, and 80 °C), milling procedure (hammer, roller, pin, and paddle), and particle size (< 250 µm and < 160 µm) on the quality, functional properties, and product potential of flour from three cassava cultivars are being evaluated. The influence of genetic variability on starch quality is also being evaluated, using starches made from cultivars chosen from the cassava core collection established at CIAT.

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† Centro Internacional de la Papa (CIP), stationed at Bogor, Indonesia.

This chapter outlines the results so far.

Materials and Methods

The cassava cultivars used in this research were selected after the cassava core collection, held at CIAT, Cali, Colombia, was evaluated (Wheatley et al., 1993). Cultivars were selected to represent a broad variability in root contents of cyanogens, dry matter, and amylose.

Experiments were designed to determine how flour preparation influences the resultant quality of the end product. In October 1992, 1,500 kg of fresh roots of the cassava cultivar CM 3306-4 were harvested at CIAT. The roots were processed into flour as outlined:

Fresh roots → Washing and peeling → Chipping → Drying → Milling → Sieving → Flour

In August and September 1993, two more cultivars of cassava (CM 3306-4, M Ven 25) were harvested 10 months after planting and similarly processed.

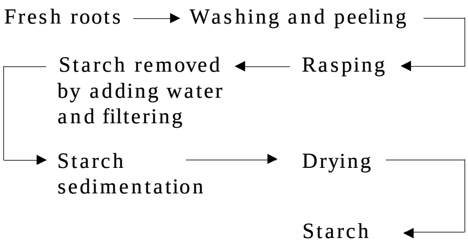
Before drying, the chips from each cultivars were divided into three lots of

475 kg. They were then dried in a layer, about 15 cm thick, on the floor (3 m^2 area) of an airflow bin dryer. Drying temperatures used were 40, 60, and 80 °C.

Four different types of mill were used to grind the resultant dry chips: (1) hammer mill (set at 5,800 rpm and with a $\frac{1}{8}$-inch screen), (2) roller mill (first pass with rollers set at 300 µm apart and second pass with rollers set at 30 µm), (3) pin mill, and (4) a paddle auger in a cylindrical sifter with a 5-mm and 250-µm screen. The flours produced were divided into two sieve fractions to give two particle sizes: smaller than 250 µm, and smaller than 106 µm.

The flours produced by the different treatments were analyzed with a Brabender amylograph (BA). Gelatinization profiles were determined from 6%-starch solutions, using a heating and cooling rate of 1.5 °C/min. The temperature was increased to 95 °C, held for 20 min, and cooled at a rate of 1.5 °C/min to 50 °C. The viscographs obtained were used to calculate the following parameters: the initial temperature of gelatinization, peak viscosity, ease of cooking, gel instability, and gelatinization index.

In October 1992, 29 cassava cultivars were harvested at CIAT 10 to 12 months after planting. Starch samples were extracted as outlined:



Starch samples were also prepared from another 33 cassava cultivars, including the same 29 cultivars, harvested at CIAT in July 1993 9 months after planting.

The starch samples extracted from the cassava cultivars in 1992 were analyzed with a BA. Gelatinization profiles were determined from 6%-starch solutions as described above. The amylose contents were determined, using an iodo-colometric test and a calibration curve prepared from potato amylose and amylopectin. The crystallinity of the starch granules was determined with an X-ray diffraction system. The diffraction data were collected over an angular range from 4° to 32° 20'.

Starch samples from both harvests will be examined for granular size distribution, amylose-to-amylopectin ratio, chain length, degree of polymerization, X-ray diffraction patterns and absolute crystallinity, differential scanning calorimetry (DSC) analysis, pasting and rheological characteristics, swelling power and solubility, and water-binding capacity.

Results

Flour

The various processing procedures used in these experiments all influenced the gelatinization profiles of the resultant flours (Figures 1 to 4; Table 1). Whether the differences obtained in gelatinization properties are enough to significantly influence the potential uses of the flours is yet to be determined. At the time of writing, the flours prepared from the cultivars harvested and processed in August and September 1993 were not yet analyzed.

Starch

Figure 5 shows a sample of the X-ray diffractograms obtained from starches

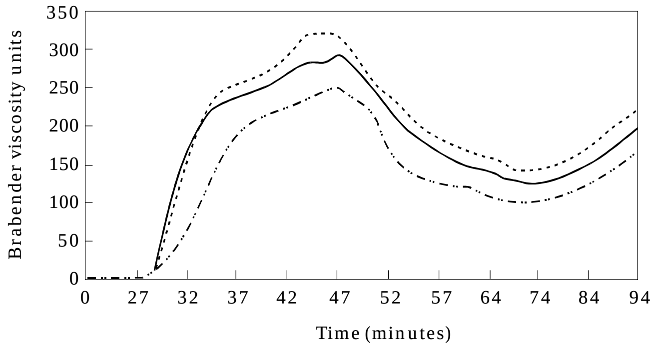


Figure 1. Viscoamylograph of cassava flour in relation to drying temperatures (–··– = 40 °C; ---- = 60 °C; —— = 80 °C). Brabender curves were obtained from flour suspension at 6% of dry matter. The flour had a particle size smaller than 250 µm, after milling with rollers.

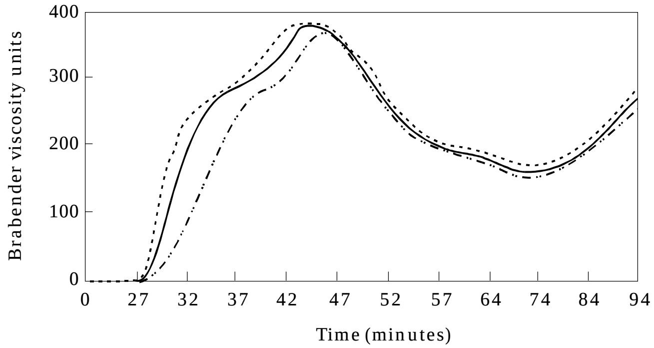


Figure 2. Viscoamylograph of cassava flour in relation to drying temperatures (–··– = 40 °C; —— = 60 °C; -----= 80 °C). Brabender curves were obtained from flour suspension at 6% of dry matter. The flour had a particle size smaller than 250 µm, after milling with a hammer mill.

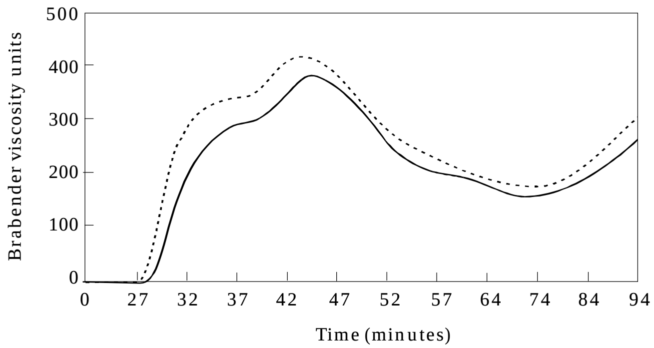


Figure 3. Viscoamylograph of cassava flour in relation to particle size (—— = 250 µm; ---- = 106 µm). Brabender curves were obtained from flour suspension at 6% of dry matter. Chips were dried at 60 °C and milled in a hammer mill.

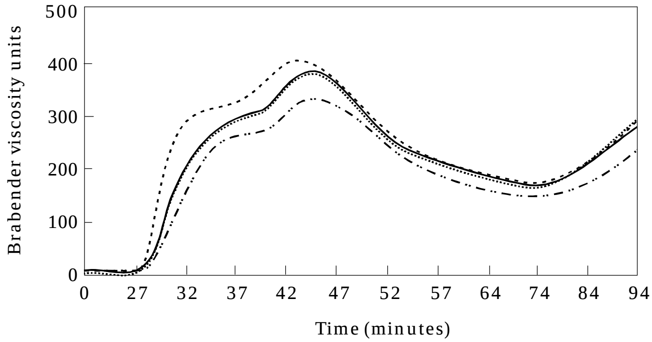


Figure 4. Viscoamylograph of cassava flour in relation to milling method (—— = hammer mill; ······ = pin mill; –··–= roller mill; – – – – = paddle mill). The flour was made from chips dried at 60 °C, and flour particle size was smaller than 250 µm. Brabender curves were obtained from flour suspension at 6% of dry matter.

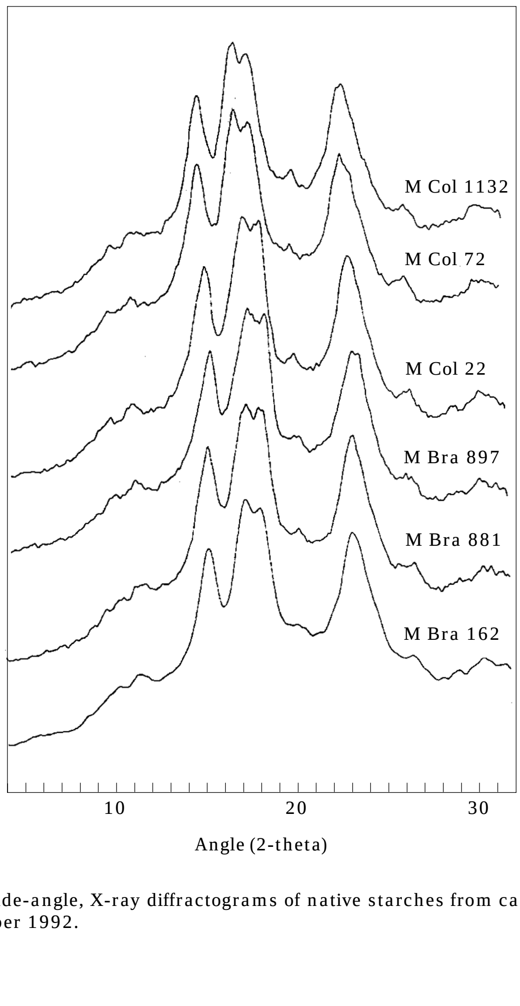


Figure 5. A sample of wide-angle, X-ray diffractograms of native starches from cassava cultivars harvested at CIAT, October 1992.

Table 1. Cassava flour functionality characteristics in relation to its particle size, the drying air temperature, and the milling procedure of the chips.

Flour characteristic	Milling equipment and drying temperatures (°C)											
	Hammer			Roller			Pin			Paddle		
	40	60	80	40	60	80	40	60	80	40	60	80
Flour composition:												
Flour A[a]:												
Starch (%, db)	83	82	79	85	83	81	84	82	81	88	86	82
Fiber (%, db)	0.9	0.8	1.0	1.4	1.0	1.6	1.2	0.7	1.3	1.0	1.2	1.3
Ash (%, db)	1.5	1.7	1.7	1.8	1.8	1.8	1.5	1.6	1.7	1.6	1.5	1.4
Flour B[b]:												
Starch (%, db)	87	85	83	86	86	86	86	86	85	92	91	87
Fiber (%, db)	0.6	0.8	0.4	0.4	0.5	0.6	1.1	0.8	1.1	0.6	0.8	1.1
Ash (%, db)	1.4	1.5	1.5	1.7	1.3	1.6	1.5	1.5	1.7	1.5	1.3	1.5
Gelatinization temperature (°C):												
Flour A	65.5	65.5	65.5	65.5	65.5	65.5	64.0	65.5	65.5	65.5	65.5	65.5
Flour B	65.5	65.5	65.5	65.5	65.5	65.5	65.5	64.0	65.5	65.5	65.5	65.5
Maximum viscosity:												
Flour A	371	380	380	255	323	295	380	380	340	408	410	410
Flour B	385	420	380	285	350	327	387	405	360	400	430	425
Viscosity at 95 °C:												
Flour A	365	365	366	251	321	289	377	363	340	390	380	385
Flour B	375	387	367	284	338	320	377	380	358	380	390	385
Viscosity after 20 min at 95 °C:												
Flour A	172	175	185	102	152	131	202	183	239	168	180	190
Flour B	177	190	185	119	160	152	177	190	228	170	185	200
Viscosity at 50 °C after cooling:												
Flour A	285	300	322	180	252	210	292	313	319	295	318	350
Flour B	308	327	320	180	285	260	297	340	335	305	340	380
Ease of cooking[c]:												
Flour A	19	17	16	20	18	20	19	17	16	17	16	15
Flour B	18	16	16	20	17	16	18	17	15	17	16	14
Gel instability[d]:												
Flour A	199	205	185	153	171	164	178	197	101	240	230	220
Flour B	208	230	195	166	190	175	210	215	132	230	245	225
Gelatinization index[e]:												
Flour A	113	125	137	78	100	79	90	130	80	127	138	160
Flour B	131	137	135	61	125	108	120	150	107	135	155	180

a. Flour A = flour with particles smaller than 250 µm.
b. Flour B = flour with particles smaller than 106 µm.
c. Ease of cooking = time to maximum viscosity - time to gelatinization.
d. Gel instability = maximum viscosity - viscosity after 20 min at 95 °C.
e. Gelatinization index = viscosity at 50 °C after cooling - viscosity after 20 min at 95 °C.

made from the roots of the October 1992 harvest. All spectra of the 29 cultivars analyzed showed an A-type, X-ray diffraction pattern. Table 2 gives values calculated for starch crystallinity and amylose content, together with the analysis reported by CIAT of root dry matter and cyanogen contents. Table 3 gives the gelatinization profiles of starch

Table 2. Dry matter of fresh roots, cyanogen content of fresh parenchyma, amylose content, and crystallinity of starch obtained from 29 cassava cultivars harvested at 10-12 months at CIAT, Palmira, Colombia, October 1992.

Cultivar	Dry matter (%)	Total cyanogens (as HCN, mg/kg, db)	Amylose (% in starch)	Crystallinity (%)[a]
M Bra 162	32	1,012	17	39
M Bra 881	31	832	20	41
M Bra 897	36	98	21	38
M Col 22	35	85	23	37
M Col 72	33	248	22	41
M Col 1132	21	69	26	39
M Col 1486	37	120	22	43
M Col 1684	37	752	23	38
M Col 2066	30	58	24	43
M Col 2215	43	243	25	44
M CR 35	45	17	24	41
M Mal 1	38	411	25	39
M Mal 2	27	413	24	40
M Mex 59	34	311	21	39
M Nga 2	22	632	23	47
M Per 196	33	393	21	42
M Tai 1	33	629	22	38
M Ven 25	27	1,628	22	43
M Ven 77	32	223	23	40
CG 1-37	35	182	22	44
CG 165-7	23	402	22	44
CG 402-11	18	169	20	45
CG 915-1	37	149	24	41
CG 1118-121	27	27	25	39
CG 1141-1	40	337	24	44
CM 489-1	23	86		41
CM 2766-5	32	82		43
CM 2772-3	27	114		42
CM 3306-4	39	82		43

a. Based on the separation and integration of the areas under the crystalline and amorphous X-ray diffraction peaks.

Table 3. Values of total cyanogen content in parenchyma, amylose content, starch crystallinity, and starch functionality characteristics for six cassava cultivars harvested in October 1992 at CIAT, Palmira, Colombia.

Characteristic	Cultivar					
	CM 3306	CG 1-37	M Ven 77	CG 165-7	M Tai 1	M Ven 25
Total cyanogen in parenchyma (as HCN, mg/kg, db)	82	182	223	402	629	1,628
Amylose (%)	26	22	23	22	22	22
Crystallinity (%)	43	44	40	44	43	43
Gelatinization temperature (°C)	64.0	64.0	65.5	62.5	62.5	62.5
Maximum viscosity	975	775	610	800	780	730
Viscosity at 95 °C	415	320	330	350	340	310
Viscosity after 20 min at 95 °C	260	225	195	220	230	190
Viscosity at 50 °C after cooling	520	460	380	435	410	330
Ease of cooking[a]	4	4	7	5	5	5
Gel instability[b]	715	550	415	580	550	540
Gelinization index[c]	260	235	185	215	180	140

a. Ease of cooking = time to maximum viscosity - time to gelatinization.

b. Gel instability = maximum viscosity - viscosity after 20 min at 95 °C.

c. Gelatinization index = viscosity at 50 °C after cooling - viscosity after 20 min at 95 °C.

samples analyzed. The results obtained show a similar trend to that reported by Wheatley et al. (1993). Differences in starch viscosity characteristics were observed between cultivars with high and low cyanogenic content.

Research is continuing with the 33 starch samples obtained from cultivars harvested in July-August 1993.

Reference

Wheatley, C. C.; Orrego, J. I.; Sánchez, T.; and Granados, E. 1993. Quality evaluation of the cassava core collection at CIAT. In: Roca, W. M. and Thro, A. M. (eds.). Proceedings of the First International Scientific Meeting of the Cassava Biotechnology Network, Cartagena de Indias, Colombia, 25-28 August 1992. Working document no. 123. CIAT, Cali, Colombia. p. 255-264.

Chapter 31

Establishing and Operating a Cassava Flour Plant on the Atlantic Coast of Colombia[1]

*Francisco Figueroa**

Background

CIAT has developed a strategy to design and implement cassava projects, integrating aspects of the crop's production, processing, and commercialization in northern Colombia. Within this framework, three phases of development can be distinguished:

(1) *Research:* developing technology for cassava processing, and studying in detail the technology's market opportunities, both on a national and regional basis.
(2) *Pilot project or market test:* producing and marketing on a small scale under real market conditions.
(3) *Commercialization or expansion:* consolidating the market for new products and replicating the processing units.

A project to develop, under this strategy, a rural cassava flour industry was begun, and its progress so far is reported here.

Results of phase I (research) indicated that, under the cost and price structures of cassava and wheat in Colombia, producing cassava flour at a price competitive with that of wheat flour was economically feasible (Tables 1, 2, and 3). Hence, the next phase, that of the pilot-project, was initiated.

In the research phase, baked products had been considered as the main market, where cassava flour would substitute 15% of wheat flour. But, because bakers saw a high risk of decreased product quality when using cassava flour, phase II was focused on other food categories where cassava flour would not present high risks.

With phase II, the production, processing, and marketing components of the cassava flour system were integrated under the real conditions of a cassava-growing region in Colombia. These results can be used by both public and private enterprises to promote the replication of rural, cassava flour-producing plants and the product's use in the national food industry.

The institutions participating in the project are CIAT, Cali; Universidad del Valle, Cali; the Fondo de Desarrollo Rural Integrado (DRI) of the Colombian Ministry of Agriculture; and the Fundación para

* Fundación para la Investigación y el Desarrollo de Tecnologías Apropiadas al Agro (FUNDIAGRO), Colombia.

1. No abstract was provided by the author.

Table 1. Variable costs (US$) of cassava flour in January 1994, Chinú, Colombia.

Item	Unit/t		Unit cost	Cost/t
Raw material	3.5	t	43.00	150.50
Labor	60	man-hours	0.40	24.00
Package	25	units	0.30	7.50
Electricity	140	kW/h	0.10	14.00
Mineral coal	550	kg	0.04	22.00
Water	7	m^3	0.40	2.80
Variable costs				220.80

Table 2. Fixed costs (US$) of cassava flour, Chinú, Colombia, January 1994.

Item	Cost/month	Cost/t
Manager[a]	123.00	6.15
Production chief[b]	12.00	0.60
Watchman	121.00	6.05
Maintenance	125.00	6.25
Other expenses	15.00	0.75
Fixed costs	396.00	19.80

a. The cost is shared by the chip and flour plants.
b. Bonus for production.

Table 3. Production costs (US$) of flour in Chinú, Colombia, January 1994.

Item	Cost/t
Variable costs	220.80
Fixed costs	19.80
Total production costs	240.60

la Investigación y el Desarrollo de Tecnologías Apropiadas al Agro (FUNDIAGRO). The donor agency is the International Development Research Centre (IDRC), Canada.

Methodology Used in the Integrated Cassava Project

The integrated cassava project is a rural development strategy. It is carried out by small-scale, rural producers and inhabitants. It is implemented in three phases, and promotes cassava's transformation in agroindustry by integrating functions of production, processing, and commercialization. It is supported by governmental and nongovernmental organizations.

Phase I of the Flour Project: Research (1985-1987)

Colombia's economic situation, the prospects for cassava, and the national potential for cassava-based products were studied to select the most promising product and choose an appropriate site. The Atlantic coastal region (northern Colombia) was also studied as having the greatest potential for developing the project. Aspects such as cassava production, farmer organizations, and markets were taken into account to choose the best site for the pilot plant.

Aim

The objective of this phase was to determine the economic and technical conditions required for the project.

Activities

Studies were made of the cassava production and marketing systems on Colombia's Atlantic coast. On-farm trials were conducted with improved cassava production technology. Economic studies were made of the wheat milling and baking industries. The experimental cassava flour plant was designed and developed. Trials were made of equipment and processing. Laboratory trials were made on flour quality and consumer acceptance.

Results

The results demonstrated the technical and economic feasibility of producing cassava flour to compete with wheat flour in Colombia.

Phase II: Pilot Project (1988-1992)

A pilot plant was set up in Chinú, Department of Córdoba (Figure 1), with technical conditions for semicommercial operation under real market conditions.

Aims

The major objective was to validate the technology under real field

Figure 1. Site for the cassava-flour production pilot plant in northern Colombia. The pilot plant is part of phase II of a project to develop new, market-oriented, cassava-based products and their markets.

conditions, integrating production, processing, and marketing. Other objectives were to (1) gather reliable data on production costs and on the investment needed to establish this type of plant; (2) produce enough cassava flour to promote its use among consumers; and (3) use the plant as a display model to expand this technology to other regions of Colombia.

Activities

The main activity was to establish the pilot plant. Criteria for site selection included aspects of cassava production, land availability, potential for increasing cassava yields, processing, raw material availability (production, seasonality, access to fresh market), service infrastructure (water, electricity, roads), proximity to terminal markets, institutional presence and support, potential project impact, and socioeconomic importance of cassava.

Alternative sites were surveyed, four potential zones selected, then a site, with farmer organizations close by, was chosen. The pilot plant was redesigned, in which combined natural and artificial drying was eliminated. A designer and builder were contracted and the redesigned plant built.

Results

The pilot plant began operating with adjustments in production, processing, and marketing. A viable and functional model was obtained.

Phase III: Commercial Expansion (1993 Onward)

A market study for the new product was designed and developed, clients were contacted, and test trials conducted with them. Commercializing cassava flour in the meat processing and adhesive industries began.

At the time of writing, project expansion to other areas of Colombia had not yet started, market expansion was still to come, together with a further consolidation of the new rural agroindustry.

Aim

The objective was to market cassava flour and consolidate a rural agroindustry that would benefit farmers, not only in northern Colombia, but also in other regions.

Activities

A marketing plan was designed and executed, and market segments selected. A bibliographical review was made of cassava flour uses. Commercial contacts were established and sales volume and conditions determined.

Results

Commercialization of cassava flour has begun. The model has been evaluated and adjusted and new sites selected. The project is expanding to other zones.

A Cooperative Carries Out the Project

The Cooperativa de Productores de los Algarrobos (COOPROALGA), based in Chinú, is a first-order organization with 43 members, all small-scale farmers dedicated to growing cassava intercropped with maize or yam. Most members pay rent for land and the remaining 20% own it.

COOPROALGA manages two plants, one producing cassava chips for animal feed, and the other the pilot cassava flour plant (Figure 2).

Characteristics of the Plant, Process, and Product

The flour plant

The cassava flour plant is a warehouse with an office, bathrooms, a tool room, a coal storage room, and areas where cassava roots are received, washed, chipped, and dried. The ground area of the plant is 2,058 m^2.

The plant has two water storage tanks, one underground with a capacity of 39 m^3 and the other elevated, holding 6 m^3. All the plant's residual waters flow in two independent lines. The plant's walls are of concrete blocks, and the roof has a metal framework and is tiled with asbestos.

Construction of the plant had cost US$29,484.00 in March 1990. The Universidad del Valle and CIAT designed the main processing equipment, which was built in Cali.

Processing

A batch process was implemented and includes the following operations: harvest, transport, reception, weighing, selecting, preparing, washing, chipping, drying, premilling, and milling. The resulting cassava flour is then packaged and stored (Table 4 and Figure 3).

Each batch is processed in 2 days. On the first day, the roots are harvested, transported, selected, and prepared. On the second day, they are washed, chipped, dried, and milled, and the resulting flour stored.

The product

Before harvesting, the farmer prunes the cassava plant, removing aerial parts, and on the next day he harvests and packs the roots, and takes them to the plant.

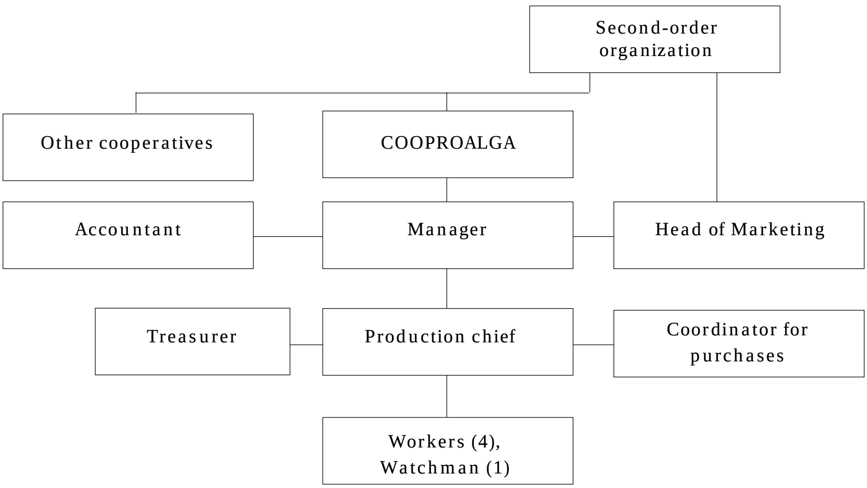


Figure 2. The organization of the pilot cassava flour plant set up in Chinú, northern Colombia.

Table 4. Processing 1 t of cassava flour in a pilot plant, Chinú, northern Colombia.

Day	Hours	Activity	Man-hours (no.)	Workers (no.)
1	5:00 - 11:00	Harvest (3.5 t)	-	-
	9:00 - 14:00	Root transportation	-	-
	9:00 - 14:00	Reception and weighing	2	1
	14:00 - 18:00	Selection and preparation	20	5
2	7:00 - 11:00	Washing and chipping	8	2
	7:00 - 11:00	Loading the drying chamber	4	1
	6:00 - 7:00	Cleaning the burners	1	1
	7:00 - 8:00	Drying starts	1	1
	8:00 - 20:00	Drying (chip turning)	20	3
3	6:00 - 7:00	Cleaning and maintenance	2	2
	6:00 - 7:00	Unloading the dryer	1	2
	7:00 - 8:00	Milling and packaging	1	2
Total			60	6

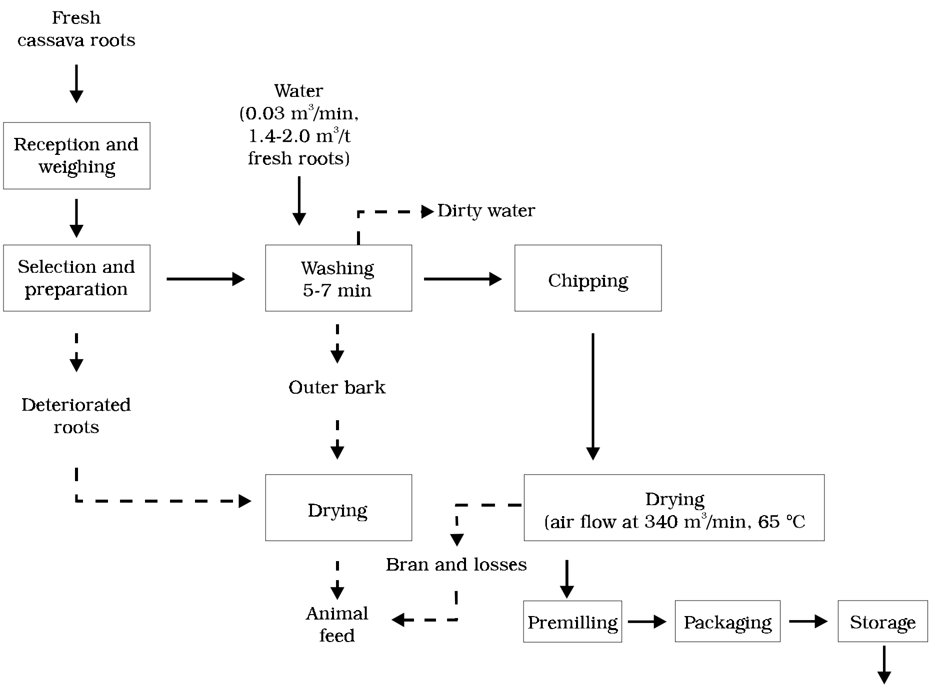


Figure 3. Procedures in cassava flour processing at the pilot plant, Chinú, northern Colombia. (Dotted lines refer to secondary processes.)

Cassava roots are received in 50 to 60 kg sacks, and should have been harvested on the day of receipt. They should also be free of diseases, deterioration, or severe mechanical damage, and should be from varieties containing high dry matter content.

After washing, chipping, drying, milling, and sieving through 150 microscreens, cassava flour is finally obtained.

CHAPTER 32

IMPROVING PROCESSING TECHNOLOGIES FOR HIGH-QUALITY CASSAVA FLOUR

D. M. Jones, D. S. Trim**, and
*C. C. Wheatley***

Abstract

The potential of cassava flour to diversify markets for cassava producers is investigated. The effects of different root processing regimes on cyanogen contents and microbiological counts—major factors governing quality in cassava flour—were investigated at CIAT. Chipping, rasping, and different drying technologies were evaluated in terms of product quality. Three types of chippers, five raspers, and drying by sun, oven, or bin were used. Rasping and drying reduced the cyanogenic glucoside contents of the roots by 90% to 100%, but microbiological counts were high for all drying technologies. The chipping trials indicate that sun drying on trays produced chips of similar microbiological quality to artificial drying.

Introduction

Cassava is grown in many parts of the developing world, mainly by small-scale farmers, for both food and income. Often such farmers have limited scope for other crops, because of harsh climate, poor soils, or both. Markets for fresh roots for direct consumption are stagnant or diminishing in many places because of increasing urbanization and changes in eating habits. Demand for roots for starch and chips for animal feed, although existing where such industries operate, is limited. Cassava flour is a product that could help diversify and strengthen cassava markets for these small producers.

The main industrial market opportunities for cassava flour are in the substitution of other raw materials, primarily wheat flour or starches, for further processing into final products. In some areas, smaller regional markets exist for local, cassava-based food specialties. To penetrate these markets, cassava flour must be of at least comparable quality to the product it is potentially replacing. Possible clients are unlikely to risk changing feed stocks if it is at all possible that the quality of their end product will be adversely affected.

Factors of Flour Quality

Microbiological quality

Wheat flour tends to be of high microbiological quality, because the economic product (the grain) develops

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above the ground; is cultivated with modern, large-scale, farming practices; and is harvested at relatively low moisture content. In contrast, cassava roots are usually cultivated with basic farming practices, picking up a microbial load from the soil, and have a much higher moisture content than grains. Hence, cassava flour is likely to have higher levels of microbiological growth.

Table 1 gives selected flour standards. The Colombian standard permits the same maximum bacterial loads for both wheat and cassava flours. Cassava flour has a lower maximum permitted moisture than wheat flour, because of its perceived greater susceptibility to contamination.

Cyanogens

Cassava flour also contains residual levels of cyanogenic compounds (cyanogens), mostly cyanogenic glucosides (CG), cyanohydrins, and hydrogen cyanide (HCN). The glucosides initially present in the fresh roots are broken down, during processing, to the other cyanogens given above (Bokanga, 1992). Cyanogen concentrations are expressed as mg HCN equivalent per kg of dry matter, unless otherwise stated. Nonglucosidic cyanogen (NGC) concentration describes the combined concentrations of cyanohydrins and HCN. The cyanogen levels remaining vary with the raw material concentration and the processing technologies employed (Fish and Trim, 1993). These levels are not a major concern for nonfood use.

Hydrogen cyanide is toxic, but is usually present only in small quantities because of its volatility. Evidence suggests that cyanide poisoning and intoxication resulting from consumption of cassava flour may be caused by high residual

Table 1. Quality standards for selected flours.

Quality criterion	Cassava flour		Wheat flour	
	Colombian[a]	African[b]	Colombian[c]	Tanzanian[d]
Chemical composition (maximum permitted levels):				
Moisture (%)	12	13	14	
Starch (% minimum)	62			
Ash (%)	2	3	0.7	
Crude fiber (%)	2.5	2	2	
Sand (%)	3	10		
Crude cellulose (%)	5			
Total HCN (mg/kg)	50			
Microbial content (cfu/g):				
Aflatoxins	0			
Aerobic plate count at 35 °C	2×10^5		2×10^5	1×10^5
Coliform bacteria	1×10^2		1×10^2	
Escherichia coli	0		0	0
Salmonella	0		0	0
Molds and yeasts	1×10^3		1×10^3	1×10^3

a. ICONTEC, 1990.
b. FAO and WHO, 1992.
c. ICONTEC, 1967.
d. Tanzania Bureau of Standards, 1989.

cyanohydrin levels, which then decompose after ingestion (Banea, 1993; Mlingi et al., 1992). The effect of consuming CG on health is less clear and has not yet been thoroughly investigated.

Few official standards exist specifically for cassava chips and flour for human consumption. The Colombian standard for dried cassava sets a maximum total cyanogen content of 50 mg/kg (fresh basis), measured as HCN (ICONTEC, 1990). The regional standard being developed for Africa (FAO and WHO, 1992) sets a maximum total cyanogen content of 10 mg/kg (fresh basis). The standards are expected to evolve with the product, and further guidance may be found in the proceedings of the Cassava Safety Workshop held in 1994.

Research on Processing Technologies

The quality of the cassava flour produced at the CIAT pilot plant was rigorously evaluated in terms of residual cyanogens and microbiological quality (results not shown). Research was then carried out at CIAT, with the following objectives:

(1) To investigate the modification of chip size as a means of increasing the elimination of total cyanogenic potential (CNP) during flour production.
The degree of cyanogen elimination achieved by the pilot plant effectively sets the maximum initial cyanogen concentration in the feed roots acceptable by a plant of this type. Increasing the elimination of cyanogens without fundamentally changing the process would ensure that the cassava flour produced meets the standard, and would increase the range of varieties that the plant's processing operations can satisfactorily detoxify. Manually peeling the roots was not investigated at this stage.

(2) To investigate means of processing high cyanide varieties of cassava into flour with safe residual cyanogen levels.
High cyanogen varieties are more suited to some agroecological zones, and are preferred to low cyanogen varieties in some regions. The operations of chipping and drying do not eliminate enough cyanogens to process high cyanogen varieties satisfactorily.

Effect of Chip Size on Residual Cyanogens in Bin-dried Chips

Methods

Trials were carried out with three different chipping disks: the standard disk (CIAT-designed); a modified version with reduced chip aperture to give thinner chips; and a grating disk designed by the Ecole nationale supérieure des industries agricoles et alimentaires (ENSIA), France (Monroy-Rivera, 1990). Roots 11 months old were harvested the day before the trial and stored outdoors overnight (normal factory plant practice). The roots were washed in a drum washer, which also effectively dehusks the roots, and chipped. The wet chips were bin-dried at 60 °C, at loading densities of 75 and 85 kg/m^2 (Figure 1). Six samples were taken from both fresh and dried chips, and analyzed with the modified Cooke method (O'Brien et al., 1991).

Results

Table 2 gives the cyanogen contents measured during these trials.

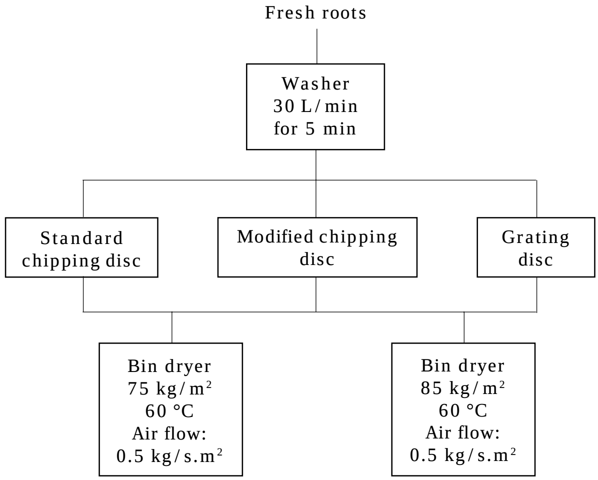

Figure 1. Procedures used in cassava-chipping trials.

Standard disk. The total CNP in the fresh chips were reduced by about 34% by chipping with the standard disk, followed by drying within 5 hours. This figure is consistent with the results obtained by using the same disk at the pilot plant, where proportionally greater reductions in CNP were achieved with longer drying times. This was despite processing a different variety under different climatic conditions.

Modified disk. The modified disk achieved a similar level of reduction in CG, but with a lower overall CNP reduction of 28%.

The modified chips had an average thickness of 4.3 mm, compared with 6.1 mm for the normal chips, providing a greater cut-surface area. A greater initial elimination of the CG was therefore expected in the modified fresh chips because of the higher percentage of damaged root tissue. Under suitable conditions, a faster drying rate was also expected, leading to surface drying of the chips in a shorter period, and earlier termination of cyanogenic reactions.

The low degree of elimination obtained with the modified chips indicates that the effect of fast drying is masking any effect of chipping, which would be more obvious at the slower drying rates obtained at higher loading densities.

Grating disk. The grating disk showed a higher reduction (56%) than the standard chipper (34%) of CNP, with chipping and drying. This is consistent with the greater extent of tissue damage achieved. Reduction of CG with chipping and drying was consistent at 59%-61%. The reduction in CG is dictated by the quantity of glucosides brought into contact with linamarase enzyme, which, in turn, depends on the extent of tissue damage. Cyanogenic glucosides in undamaged tissue remain intact. The chips produced by the grating disk were more fragile than the pilot plant ones and less suitable for bin drying.

Table 2. Cyanogen concentrations[a] measured during cassava chipping trials[b].

Cyanogenic contents	Standard disk at loading density (kg/m²):						Modified disk at loading density of 85 kg/m²			Grating disk at loading density (kg/m²):					
	85			75						85			75		
	CNP	NGC	CG	CNP	NGC	CG	CNP	NGC	CG	CNP	NGC	CG	CNP	NGC	CG
Fresh chips (mg HCN equiv./kg dry matter)	1,269	253	1,016	1,096	172	924	832	152	680	858	320	539	1,118	198	920
Dried chips (mg HCN equiv./kg dry matter)	812	35	776	746	38	709	598	7	591	396	40	356	480	41	439
Reduction with chipping (%)			20			16			18			37			18
Reduction with chipping and drying (%)	36		39	32		35	28		29	54		59	57		61

a. CNP = total cyanogen potential; NGC = nonglucosidic cyanogen content; CG = cyanogenic glucoside content.

b. Each value is an average of six samples; percentage of reduction in both CNP and CG is based on fresh chips CNP; all trials used roots of M Ven 25, a high cyanogen variety.

Summary

Elimination of CNP from chips made by the standard disk increased with drying time, regardless of cassava variety or location.

The grating disk eliminated 22% more CNP than the pilot plant disk at the same loading density. Grated chips, however, are more fragile than standard chips and less suitable for bin drying.

Effect of Different Raspers on Residual CNP in Tray-Dried Pulps

The effect of different raspers on the degree of cyanogen elimination achieved with rasping and drying was investigated. Rasping almost completely destroys the root tissue structure, much more so than chipping. The trials used roots of M Ven 25, a very high cyanogen variety, to establish the upper limits of cyanogen elimination.

Methods

Five different raspers were used:

(1) A conventional, wooden Jahn rasper, in which serrated blades are mounted laterally on a wooden drum.
(2) A punched-drum rasper, consisting of a metal sheet with outward facing jagged holes (punched through with a nail), fixed around a wooden drum frame.
(3) A pin rasper (experimental), a metal drum scored diagonally in both directions across its length with metal pins protruding about 5 mm from the drum's surface.
(4) An abrasion rasper (experimental), with a layer of carborundum, about 10 mm deep, fixed around a drum.
(5) A plastic, Jahn rasper (experimental), in which metal serrated blades are mounted laterally on a plastic drum.

Four of the rasper drums tested were interchangeable within the same rasper frame, designed to investigate their relative starch extraction efficiency. The drums were 400 mm in length and 270 mm in diameter. The plastic Jahn rasper drum was a smaller, self-contained unit, 275 mm in length and 200 mm in diameter. An ordinary 5-HP motor was used for all the raspers. The wooden Jahn rasper and the punched-drum rasper are in common use in the cassava starch industry.

Roots were harvested at 9 months and stored as for the chipping trials. The roots were washed in clean but untreated water and dehusked manually. Fifteen kilograms of the washed roots were rasped without adding water. The resulting pulp was mixed and dried at 8 kg/m^2 on two trays in a despatch tray dryer at 60 °C (Figure 2). Four samples each of the fresh and dried pulps were taken for evaluation of cyanogen concentrations. This procedure was followed for each rasper.

Results

Table 3 gives the cyanogen concentrations measured during this trial.

Cyanogen contents of rasped pulps. The reduction in CG with rasping only was variable, with both the Jahn raspers reducing the CG by 65%, and the punched drum by 43%. When the pulps were both rasped and dried, the CNPs were reduced by 94%-96% for all raspers, regardless of the degree of reduction effected by rasping alone. The residual CNPs in the pulps ranged

Table 3. Cyanogen concentrations[a] during cassava-rasping trials, measured in mg CN equiv./kg dry matter[b].

Rasper drum		Fresh roots			Fresh pulp			Dried pulp			Reduction of CG with rasping (%)	Reduction with rasping and drying (%)	
Type	Feed (kg/min)	CNP	NGC	CG	CNP	NGC	CG	CNP	NGC	CG		CNP	CG
Wooden Jahn	28.6	2,318	271	2,047	2,195	1,409	786	104	29	74	66	96	97
Punched drum	32.6	2,417	243	2,175	2,267	968	1,299	152	88	64	46	94	97
Abrasion	2.1	2,024	235	1,789	1,932	1,372	559	132	29	103	72	94	95
Metal pin	15.0	2,608	315	2,293	2,236	881	1,355	163	27	137	48	94	95
Plastic Jahn	N/A	2,234	293	1,941	2,045	1,358	687	111	25	87	69	95	96

a. CNP = total cyanogenic potential; NGC = nonglucosidic cyanogen content; CG = cyanogenic glucoside content.

b. Each value is an average of six samples of fresh roots and four samples of pulp; percentage of reduction in both CNP and CG is based on fresh root CNP; all trials used roots of M Ven 25, a high cyanogen variety.

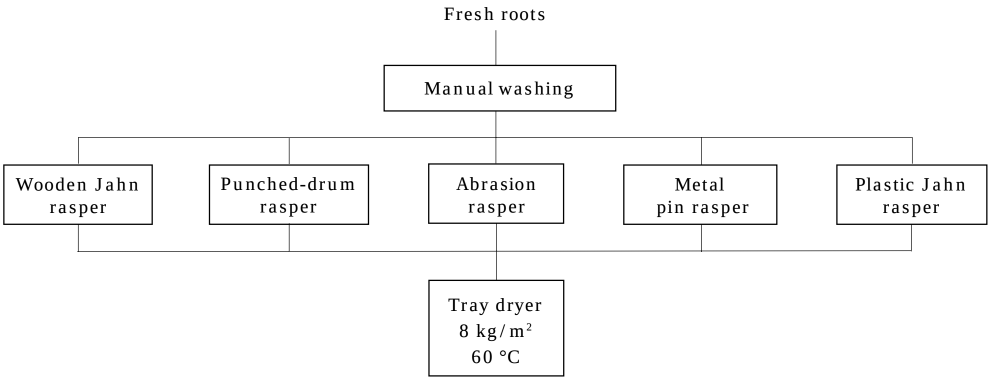

Figure 2. Procedures used in cassava-rasping trials.

from 104 to 163 mg/kg. In previous milling trials, the residual CNP concentration in first-grade flour was about 36% of the level in freshly dried chips. Assuming this to hold true for pulps, the flours would have CNPs between 38 and 58 mg/kg, thus mostly meeting the Colombian standard of 50 mg/kg.

This level of total cyanogen elimination probably approaches the maximum possible in practice, given that variations occur because of fluctuating conditions. No significant differences in the overall elimination of CNPs was found between the raspers.

Root throughput. The abrasion rasper's root feed was 10% below that of the Jahn or punched-drum raspers, thus making it unsuitable for commercial flour production. The shredding action employed by both the Jahn and punched-drum raspers removes a deeper layer of root tissue with each contact than does the erosive action of the abrasion rasper, resulting in a larger root feed.

The pulp produced by the abrasion rasper was finer and more homogenous than the other pulps, indicating a greater degree of tissue comminution. However, the final reduction in CNP achieved with the abrasion rasper was not significantly different to that achieved with the other raspers. The pulp was also more liquid and difficult to handle than the others.

Summary

Except for the abrasion rasper, the raspers evaluated were suitable for processing roots with high cyanogen contents to flour with low cyanogen content. The wooden Jahn and the punched-drum raspers are commercially available.

Effect of Different Drying Techniques on Residual Cyanogens and the Microbiological Quality of Dried Pulps and Chips

The effects of different drying techniques (sun and artificial) on the microbiological quality and on the cyanogen concentrations of chips and rasped pulps were evaluated.

Rasped pulp is not suitable for bin drying, and the effect of rasping on the microbiological quality of the dried product is unknown. Because smaller operations may not be able to justify the investment and cost of artificial drying, the effect of sun drying on the microbiological quality of products was also evaluated.

Methods

Three trials were carried out on 10-month-old roots of cassava variety M Ven 25. The first two trials used the wooden Jahn and punched-drum raspers for root comminution. The roots were washed and dry-rasped as in the rasping trials described above. The pulps were dried at loading densities of 5 and 10 kg/m^2 on raised trays and on a concrete floor in the sun, and in an oven at 60 °C. The final trial was carried out with the modified chipper, with the chips dried at 5 kg/m^2 in the same way (Figure 3). Chips were also bin-dried at 70 kg/m^2 and 60 °C (Figure 4). The chips and pulps were mixed manually every 2 h during drying. Three composite samples of each dried product were taken for microbiological analysis. The samples were analyzed for aerobic plate counts (APC) (35 °C), spore counts (35 °C), and yeasts and molds the following day (ICMSF, 1978). Four samples each of the fresh and dried pulps were also taken for cyanogen evaluation.

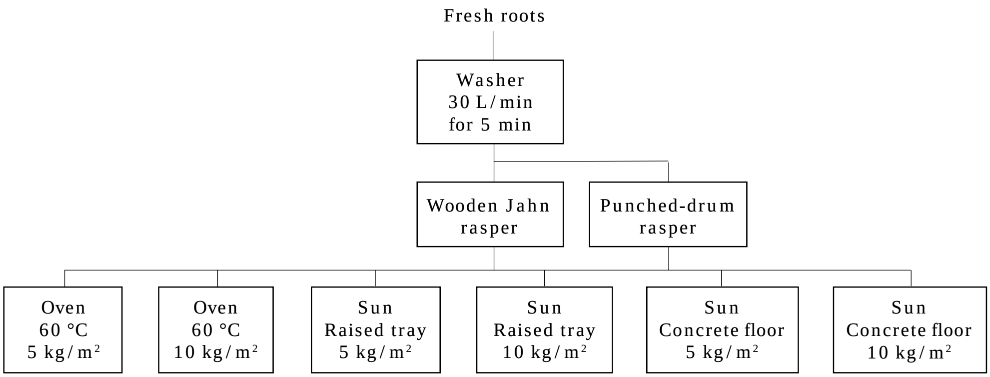

Figure 3. Procedures used in cassava rasping and drying trials.

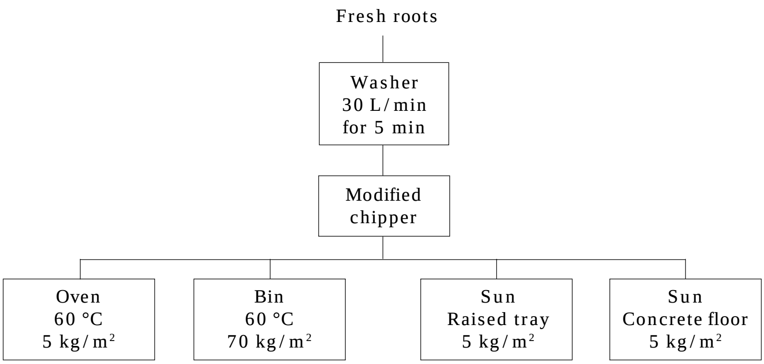

Figure 4. Procedures used in cassava chipping and drying trials.

Results

Table 4 gives the cyanogen concentrations measured during the trials and Table 5, the microbiological counts.

Cyanogenic contents of dried chips and pulps. Compared with the rasping-only trials, the punched drum reduced CG (88%) more than the wooden Jahn rasper (53%). Rasping and drying reduced the CG by 90%-100%. Sun-dried pulps tended to have higher residual NGC than did oven-dried pulps, possibly because of the higher rate of removal of HCN during forced-circulation oven drying, which would increase the rate of breakdown of cyanohydrin to HCN. Residual cyanohydrin levels tend to drop with storage and may also be reduced by the heat generated by milling to flour.

Microbiological quality of dry pulps and chips. All of the dried, rasped, pulp samples had high APCs (10^8 cfu/g), as did the chips which were sun dried on a concrete floor. The oven-dried, and raised-tray, sun-dried chips were of acceptable quality (10^5 cfu/g), and the bin-dried chips had only slightly higher counts. The rasped pulps provide a better substrate for microbial growth than the chips, as the cell contents (e.g., sugars and proteins) have all been released by rasping.

However, the APCs of fresh chips have been measured at around

Table 4. Cyanogen concentrations[a] during drying trials (rasped pulp only), measured in mg CN equiv./kg dry matter[b].

Cyanide concentration	Pulp sample from:									
	Wooden Jahn rasper					Punched-drum rasper				
	CNP	NGC	CG	Reduction with rasping and drying (%)		CNP	NGC	CG	Reduction with rasping and drying (%)	
				CNP	CG				CNP	CG
Fresh pulp	1,302	696	606		54	1,562	1,383	179		87
Dried pulp:										
Oven, 5 kg/m², 60 °C	154	30	124	88	91	37	17	20	98	99
Oven, 10 kg/m², 60 °C	105	31	74	92	94	33	28	5	98	>99
Sun, 5 kg/m², raised tray	99	47	52	92	96	53	45	7	97	>99
Sun, 10 kg/m², raised tray	67	51	15	95	99	60	50	9	96	99
Sun, 5 kg/m², concrete floor	84	77	8	94	99	68	61	7	96	>99
Sun, 10 kg/m², concrete floor	85	82	3	95	>99	81	73	8	95	99

a. CNP = total cyanogenic potential; NGC = nonglucosidic cyanogen content; CG = cyanogenic glucoside content.

b. Each value is an average of six samples of fresh roots and four samples of pulp; percentage of reduction in both CNP and CG is based on fresh pulp CNP; all trials used roots of M Ven 25, a high cyanogen variety.

Table 5. Microbiological quality of dried pulp and chips generated in cassava-drying trials.

Rasping and drying method	Loading density (kg/m²)	Microbiological count[a]		
		Aerobic plate count at 35 °C	Spore count at 35 °C	Yeast and mold count
Wooden Jahn rasper:				
Oven, 60 °C	5	3.43×10^8	3.18×10^5	4.99×10^4
Oven, 60 °C	10	3.58×10^8	2.61×10^5	5.40×10^4
Sun, raised tray	5	4.57×10^8	6.63×10^4	8.18×10^4
Sun, raised tray	10	2.95×10^8	3.10×10^4	5.64×10^4
Sun, floor	5	5.64×10^8	9.20×10^4	1.03×10^5
Sun, floor	10	3.51×10^8	3.28×10^4	3.08×10^4
Punched-drum rasper:				
Oven, 60 °C	5	1.01×10^8	8.02×10^4	6.33×10^3
Oven, 60 °C	10	2.12×10^8	3.74×10^4	2.65×10^4
Sun, raised tray	5	2.08×10^8	2.84×10^4	5.48×10^4
Sun, raised tray	10	5.24×10^8	1.92×10^4	1.97×10^5
Sun, floor	5	1.13×10^8	1.38×10^4	1.15×10^5
Sun, floor	10	5.93×10^8	1.87×10^4	7.13×10^4
Modified chipper:				
Oven, 60 °C	5	5.45×10^5	4.50×10^2	2.67×10^2
Bin, 60 °C	70	2.04×10^6	8.67×10^2	7.33×10^2
Sun, raised tray	5	2.18×10^5	3.33×10^2	1.33×10^2
Sun, floor	5	4.01×10^8	1.71×10^5	2.15×10^5

a. Counts expressed as colony forming units per gram (cfu/g), wet weight basis; average of three composite samples.

10^5 cfu/g (Table 6). Previous pilot-plant experience has shown that, with long drying times (22 h), the APCs of the chips are at 10^8 cfu/g, but reducing the drying time to 10 h reduces the APCs to 10^5 cfu/g. Faster drying of the pulp may therefore offer a means of reducing the counts. The shortest pulp drying time of 6 h was insufficient to affect the counts.

Raised-tray sun drying of chips gave a product of good microbiological quality with APCs similar to those of oven-dried chips. Thus, this method may have potential for reducing costs under suitable climatic conditions (site specific).

Summary

Rasping and drying of cassava roots is an effective means of reducing the CNP present in high cyanogen cassava varieties. However, the greater degree of root disintegration leads to increased microbiological growth.

Conclusions

Processing with the grating disk reduced CNP by 22% more than the standard disk. However, drying grated chips at high loading densities may be difficult.

Fast drying stopped the elimination of cyanogens early in the

Table 6. Microbiological quality of processed samples from pilot plant and CIAT trials, November 1991.

Sample	Microbiological counts[a]			
	Aerobic plate count at 35 °C	Spore count at 35 °C	Coliforms (MPN[b])	Fecal coli-forms (MPN[b])
CIAT:				
Soil	7.7×10^7	8.1×10^5	$>1.1 \times 10^3$	15
Root peel[c]	3.0×10^7	6.2×10^4	$>1.1 \times 10^3$	<3
Parenchyma	1.2×10^3	1.5×10^2	<3	<3
Pilot plant:				
Soil	6.8×10^7	5.7×10^7	$>1.1 \times 10^3$	40
Root peel[c]	1.4×10^7	3.0×10^5	$>1.1 \times 10^3$	7
Well water	4.6×10^3	8.3×10^1	<3	<3
Tank water[d]	4.7×10^3	2.6×10^2	<3	<3
Fresh chips	4.9×10^5	2.8×10^3	1.1×10^3	500

a. Counts expressed as cfu/g (wet weight basis) for processed samples and as cfu/ml for water samples.
b. MPN = most probable number.
c. Root peel includes bark and peel.
d. Tank water treated with 10-20 mg/L free chlorine.

SOURCE: D. S. Trim and P. Wareing, 1991, personal communication.

drying period of the modified-disk chips, masking any effect chip size might have had. Greater reduction in CNP is likely at higher loading densities.

Rasping and drying is an effective means of processing even very high cyanogen roots to a flour that meets the Colombian standard. Further work is needed to improve the product’s microbiological quality.

In suitable climatic conditions, raised-tray sun drying of chips gives a product of good microbiological quality.

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CHAPTER 33

CASSAVA FLOUR IN MALAWI: PROCESSING, QUALITY, AND USES

*J. D. Kalenga Saka**

Abstract

The quality of flour processed from cassava (*Manihot esculenta* Crantz) by two methods commonly used in Malawi was determined. The first, simple sun-drying, gives a flour known as *ntandaza*; the other—soaking in water, followed by sun drying—provides *kondowole* flour. Processing affects both the nutritional quality and cyanogen content of the final products. The soaking step significantly reduces mineral and protein contents and raises the carbohydrate level ($P > 0.05$) to 91.1% ± 1.1% for *ntandaza* flour and 95.3% ± 0.7% for *kondowole*.

The soaking step, followed by sun drying, reduces the cyanogen content more than sun drying alone. In soaking + sun drying, less than 10 mg HCN/kg dry wt were detected in the final products, representing a 98.0% ± 1.6% reduction of initial cyanogen content. Simple sun drying reduced total cyanogen content by 82.9% ± 5.2%.

The uses of cassava flour in bakery, brewing, and making cassava *sima* are described.

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Introduction

Cassava (*Manihot esculenta* Crantz) is a major root crop in the tropics, and its starchy roots are a significant source of calories for more than 500 million people worldwide (Cock, 1985). In Malawi, cassava is the second most important staple after maize (DEPD, 1987): about 30% of the population depends on cassava for calories (Sauti, 1982). The crop grows easily in all parts of the country, but especially along the shores of Lake Malawi where it is the most important staple food. Since the 1991/92 drought, which devastated Malawi, the Government has intensified the country's production of cassava, a drought-resistant crop, to guarantee food security.

Cassava is eaten in various forms; these determine the methods of processing, which aim to (1) provide products that are storable and easy to transport to market; (2) improve the taste of final products; (3) reduce potential cassava toxicity; and (4) provide products such as flour for subsequent conversion to a variety of end products (Hahn, 1989; Lancaster et al., 1982). In Malawi, two methods are employed to make cassava flour, resulting in two kinds of flour: *kondowole* and *ntandaza* (Saka, n.d.; Williamson, 1975).

Kondowole flour is prepared by soaking peeled cassava roots for 2 to 7 days; sun drying the soft mass (called *maphumu*) and pounding the dried mass to make the flour (Figure 1). This product is popular among lakeshore populations living in Karonga District to as far south as Nkhotakota District (Figure 2). The soaking of unpeeled roots is also practiced, but the flour gives products which taste bitter and appear darker. The flour is used in its pure form or is mixed with cereal flours (maize, sorghum, millet, wheat, or rice).

Among other things, the flour is used to make *sima*. Its preparation involves adding the flour to simmering water and stirring the paste to consistency. Both pure and composite flours are used for brewing sweet and alcoholic beverages. When mixed with wheat flour, the composite flour is widely used to bake breads, scones, cakes, and biscuits. The pure *kondowole* flour is also used in baking. When mixed with cereal flour, the nutritional value of the cassava-based products improves (Sauti et al., 1989).

Ntandaza flour is made by sun drying peeled and/or partially peeled roots for 1 week or several months. The roots may be dried whole, as cut pieces, or after pounding; the last dries fastest. The dried product is called *makaka* and the resultant flour is commonly known as *ntandaza*. The flour is also referred to as *ntandasha* and *mtandasha*, depending on the locality.

This method of processing cassava is predominant in central and southern Malawi (Figures 2 and 3). A variation of the methodology involves first covering the cassava roots with banana leaves to induce mold formation. The moldy product is then sun dried to provide a darker and moldy *makaka* (Van Drongelen, 1992).

Although the *ntandaza* flour is used in the same way as *kondowole* flour, its most important use is in

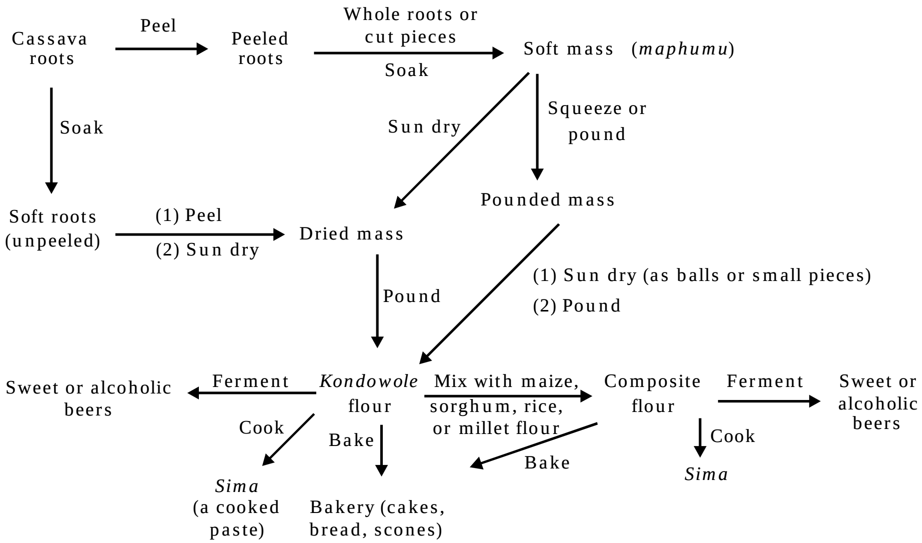

Figure 1. Processing *kondowole* flour from cassava roots, and its uses, Malawi.

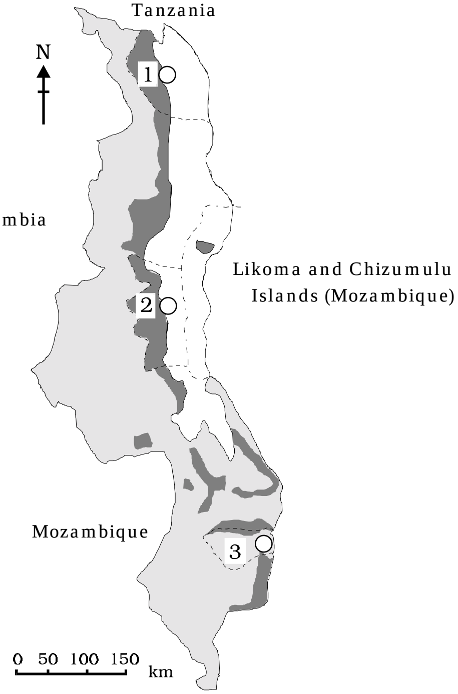

Figure 2. Cassava-growing areas in Malawi (■ = major growing areas; □ = scattered crops; □ = lake). 1 = Karonga District; 2 = Nkhotakota District; 3 = Zomba District; ○ = town of same name as district. (After Nyirenda.)

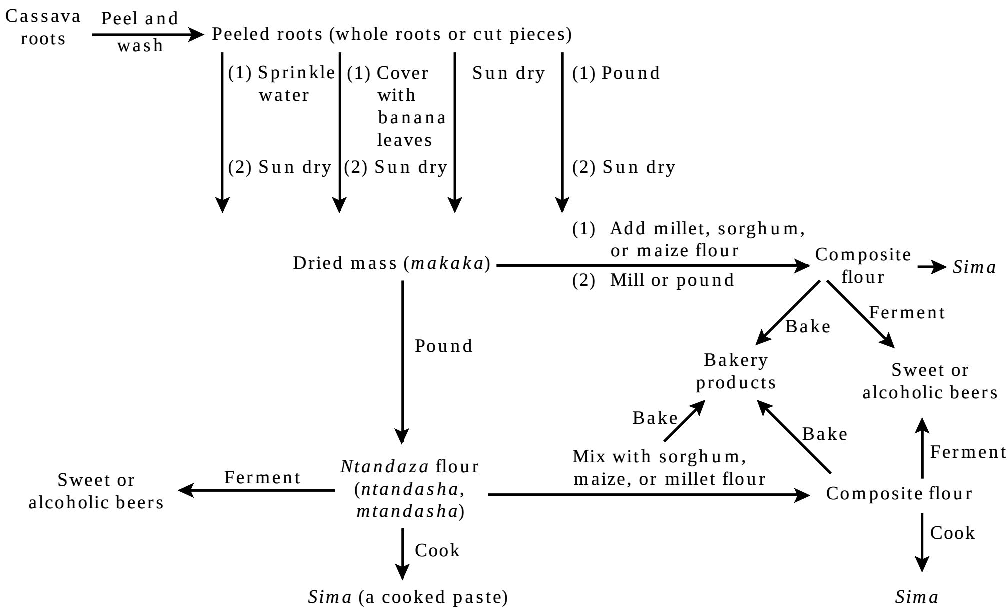

Figure 3. Processing *ntandaza* flour from cassava roots, and its uses, Malawi.

brewing. The resulting beer is reported to be of superior quality.

Information on the quality of cassava flour produced in Malawi was limited until 1986, when our work began (Saka, n.d.). The processing of cassava into various forms affects the nutritional value of the final products (Longe, 1980). The levels of total cyanoglucosides, linamarin and lotaustralin are also affected during processing (Lancaster et al., 1982).

Hydrolysis of cyanoglucosides by an endogenous enzyme, linamarase, liberates the highly toxic substance, hydrocyanic acid (HCN) via acetocyanohydrin (de Bruijn, 1971). The presence of nonglucosidic cyanogens (NGC; acetocyanohydrin and HCN) limits cassava use (Nartey, 1978). Cyanide has a lethal dose of 0.5 to 3.5 mg HCN/kg of body weight. Although the reports of acute cyanide intoxication and death among cassava-eating populations are infrequent, ample evidence exists that goiter and cretinism (due to iodine deficiency) are exacerbated, and that diseases such as tropic ataxic neuropathy and epidemic spastic paraparesis (*konzo*) are caused by long-term ingestion of cyanide from cassava (Rosling, 1987).

We studied the nutritional value and cyanogen content of the two Malawian cassava flours to ascertain their quality.

Material and Methods

Cassava samples

Tuberous roots were obtained from the Makoka Agricultural Research Station, Zomba, and from the "D. C. Munthali" Research Farm, Biology Department, Chancellor College, Zomba. The roots analyzed for nutritional value were from 12-month-old plants, whereas those processed into *kondowole* and *ntandaza* flours for cyanogen determination varied from 20 to 22 months in age.

Processing the flours

Kondowole. Four roots from each of three plants, totalling 12, from each of three varieties were peeled, washed, and soaked in deionized water (volume not recorded) in plastic wash basins for 7 days. The resulting soft mass was washed with clean water, broken down (by hand) into small pieces while removing floury material in the process, and left to dry on trays in the sun for 7 days. The dried product was then ground in a blender and sieved.

The data (Tables 1 and 2) obtained for *kondowole* flour were taken from 20 to 22-month-old plants and the soft, soaked roots were made into balls and sun dried for 67 h. Samples of *kondowole* flour were provided by the Cassava Commodity Team, Makoka Agricultural Research Station.

Ntandaza. Twelve roots were selected as above, peeled, and either pounded or cut longitudinally and transversely to produce chips. The chips were sun-dried on trays and the dried material (*makaka*) was processed into flour, using a blender and sieve. The pounded roots were sun dried for 2 to 3 days (Table 1).

Chemical analysis

Analar grade chemicals and solvents were used. Fresh roots and cassava flours were analyzed for moisture, ash, crude fiber, fat, crude protein, and minerals (Ca, P, Mg, and K), using standard procedures (Osborne and Voogt, 1978). The carbohydrate content was calculated by difference.

Table 1. Cyanogen content of cassava flours (mg HCN/kg dry wt) produced in Malawi. Values are means of samples, with SE in parentheses.

Flour type	Moisture (%)	Cyanogens			Total cyanogen reduction (% of initial content)
		Total	Non-glucosidic	Free	
Kondowole (n = 21)	11.8	2.91	0.75	0.69	98.0
Ntandaza (n = 8):					
Pounded[a], sun dried	11.4 (1.2)	116.8 (6.2)	25.5 (0.7)	1.6 (0.2)	79.7 (1.3)
Pounded[b], sun dried	4.88 (0.12)	54.4 (2.5)	4.80 (0.20)	0.39 (0.06)	80.0 (2.5)
Chips[c], sun dried	14.6 (0.5)	51.6 (3.1)	12.4 (0.6)	3.05 (0.20)	88.9 (1.0)

a. 'Nyambi', a bitter variety, was peeled, pounded, and sun dried at 30 ± 1 °C for 48 h.
b. 'Gomani', a bitter variety, was peeled, pounded and sun dried at 30 ± 1 °C for 72 h.
c. 'TMS 1230158 (OP)', a bitter variety, was peeled, cut into chips and sun dried at 30 ± 1 °C for 72 h.

Table 2. Composition of cassava roots and products from our work and some literature sources (on dry wt basis). Each value is the mean of 12 roots with ± SE.

Component	Roots (Malawi study)	*Ntandaza* flour		*Kondowole* flour		
		Malawi study	Longe, 1980	Malawi study	Williamson, 1975	Longe, 1980
Moisture (%)	55.9 ± 4.9	13.44 ± 2.66	11.80	10.77 ± 2.72	12.00	12.00
Ash (%)	2.21 ± 0.45	2.15 ± 0.18	2.05	0.91 ± 0.30		1.79
Crude fat (%)	1.23 ± 0.44	0.87 ± 0.33	0.46	0.70 ± 0.30		0.24
Crude fiber (%)	2.29 ± 0.39	2.30 ± 0.70		1.62 ± 0.30		
Crude protein (%)	3.17 ± 0.62	3.39 ± 0.73	2.04	1.46 ± 0.30	1.70	1.51
Carbohydrate (%)	91.1 ± 1.2	91.0 ± 1.1	90.30	95.3 ± 0.66	95.50	94.40
P (mg/100 g)	82 ± 35	93 ± 27		40 ± 20		
Ca (mg/100 g)	54 ± 27	26 ± 12		17 ± 8	63.00	
Mg (mg/100 g)	40 ± 17	58 ± 16		32 ± 13		
K (mg/100 g)	768 ± 354	877 ± 358		330 ± 138		

Cyanogen extraction and analysis

To 30 g of flour (60 g fresh roots) in a blender was added 0.1 *M* of chilled orthophosphoric acid (H_3PO_4) (200 cm^3), with subsequent extraction according to Cooke's (1978) method. The milky liquid was poured into centrifuge tubes. Their weights were adjusted until equal and the tubes were then centrifuged at 8 x 10^3 *g* for 10 minutes. The supernatant was collected in sample bottles and deep-frozen until analysis. The fresh cassava was extracted in four replicates and the processed cassava in duplicates. For the assay of total cyanogen content, samples were prepared according to the acid hydrolysis method of Bradbury et al.

(1991). For NGC (cyanohydrin plus free HCN) and free cyanide, the procedure of O'Brien et al. (1991) was used. In all cyanogen assays, a sodium isonicotinate-sodium dimethylbarbiturate coloring reagent was used (Saka, 1992).

The moisture contents of fresh and processed cassava were determined gravimetrically after oven drying three replicate, 10-g-sample aliquots at 110 ± 5 °C for 16 h.

Results and Discussion

Table 2 presents the mean chemical data for *kondowole* and *ntandaza* flours and the literature data for cassava flours similarly processed. The results show that, despite certain similarities, the chemical compositions of the two flours were significantly different at P = 0.05.

At 1% level, neither the fat values nor the Ca content were significantly different. The chemical data in Table 2 reveal that, compared with fresh roots, the two cassava flours are equally important sources of carbohydrates, but with generally lower values in protein, fat, and fiber. Their mean nutritional values compare well with published data (Longe, 1980) but higher fat levels were obtained by Saka (n.d.). The present data fill several gaps and also confirm the limited available information on Malawi cassava flour (Williamson, 1975).

Comparison of the chemical composition of fresh roots (Saka, n.d.) and the two cassava flours (Table 2) indicates that sun drying alone, and soaking in water followed by sun drying, affect the nutritional value of cassava. Simple sun drying produced *ntandaza* flour, whose dry matter, fat, Ca, and Mg levels were significantly different (at P = 0.05) from those of fresh roots. Whereas the dry matter and Mg contents were increased, the fat and Ca levels were decreased.

Soaking and subsequent sun drying of cassava provided *kondowole* flour, whose composition was significantly different (at both P = 0.05 and 0.01) from that of fresh roots. During this process, the carbohydrate content became significantly higher while the rest of the analyzed constituents decreased. These were lost as dissolved material during soaking. These findings are consistent with those reported by Longe (1980).

Table 1 provides the levels of total, nonglucosidic, and free cyanogens of *kondowole* and *ntandaza* flours and presents the percentage reductions in total cyanogen content. The results show that the method used to prepare *kondowole* flour (involving a submerged fermentation stage) was more efficient in reducing total cyanogen content than that employed for *ntandaza* flour. The production of *kondowole* resulted in 98.0% ± 1.6% loss in the total cyanogen content while an 82.9% ± 5.2% reduction was achieved during the processing of *ntandaza* flour.

Mahungu et al. (1987) also noted a 99% reduction in cyanogen content with methods that involve soaking roots in water. Saka (1992) recently eliminated 70% to 80% of total cyanogen content by sun drying 1-cm^3 cassava chips for 48 h. The residual, total cyanogen content of *kondowole* flour was 2.91 ± 1.44 mg HCN/kg dry wt and of *ntandaza* flour, 51.6 ± 3.1 to 116.8 ± 6.2. Thus, the *ntandaza* flour contained much higher residual cyanogen content than did the *kondowole*. The final cyanogen content depends on whether the variety contains low ("sweet") or high ("bitter") cyanogen.

The less bitter, or sweet, varieties have lower residual cyanogen content when sun dried (Saka, n.d.).

The composition of the three forms of cyanogens indicates that free HCN is a major component of the NGC in *kondowole* flour. In contrast, in *ntandaza*, cyanohydrin is the major component. Cyanoglucosides also predominate in *ntandaza* flour.

High levels of acetocyanohydrin in sun-dried chips have also been observed by others (Mlingi et al., 1992). Consumption of this type of cassava appears to lead to high thiocyanate levels in human urine (Mlingi et al., 1992). Plans are currently under way to develop or upgrade methods for reducing total residual cyanogen and cyanohydrin to levels comparable with those in *kondowole* flour.

Conclusions

Cassava and its flours are major sources of carbohydrates, but have low values in protein, fat, and minerals. The protein content could be improved by fortifying with cereal and legume grains. The use of cassava flour in Malawi remains restricted to cooking *sima*, baking, and brewing. Diversifying and promoting cassava flour use is desirable.

Soaking and subsequent sun drying of cassava roots greatly reduce the high cyanogen levels to low, safe values for human consumption. This method increased the carbohydrate content of the cassava, but other nutrients were reduced considerably. Simple sun drying was less effective in reducing total cyanogens, especially when the initial cyanogen content was high. The final products may remain potentially toxic for human consumption. Pounding of fresh cassava and its subsequent sun drying seem to offer better prospects in achieving low cyanogen content.

Acknowledgments

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SESSION 6:

NEW PRODUCTS

CHAPTER 34

THE POTENTIAL FOR NEW CASSAVA PRODUCTS IN BRAZIL[1]

G. Chuzel, N. Zakhia***, and *M. P. Cereda****

Introduction

Cassava is an important crop in Brazil, with an annual production of 22-25 million tons. Production systems, processing methods, and the degree of technology employed vary between the four major cassava regions (Amazônia, Northeast, Central South, South), according to agroecological location and socioeconomic conditions. *Farinha*, a toasted flour, comprises the principal market, accounting for 70%-80% of cassava production, but price and demand fluctuate greatly.

Price fluctuations influence the area of land cultivated, adoption of new technology for production, and income of cassava producers, mainly small-scale farmers. Diversification would help stabilize prices of both cassava flour and fresh roots. Establishing new markets for cassava and its products would enhance the value of cassava cultivation and establish important links between small-scale agriculture and expanding markets.

Given the various intermediate products of cassava (e.g., chips, flours, and starch); the array of current applications in human and animal nutrition and in industry; and the numerous traditional cassava preparations, it is possible to visualize a broad range of cassava-based markets. The key lies with new technologies and the development of novel products to fit current and potential markets.

To innovate products within the existing matrix of traditional and new products and their respective markets, the following factors should be considered:

(1) The evolution of a successful starch sector such as that of France during the last 20 years;
(2) Current trends in Brazil toward product diversification; and
(3) Proposed strategies for the short and medium terms.

The Evolution of the Starch Sector in France

The modern French starch industry, based on maize or potato starch, provides a relevant example of an industry evolving in search of new products and markets in both food and nonfood sectors.

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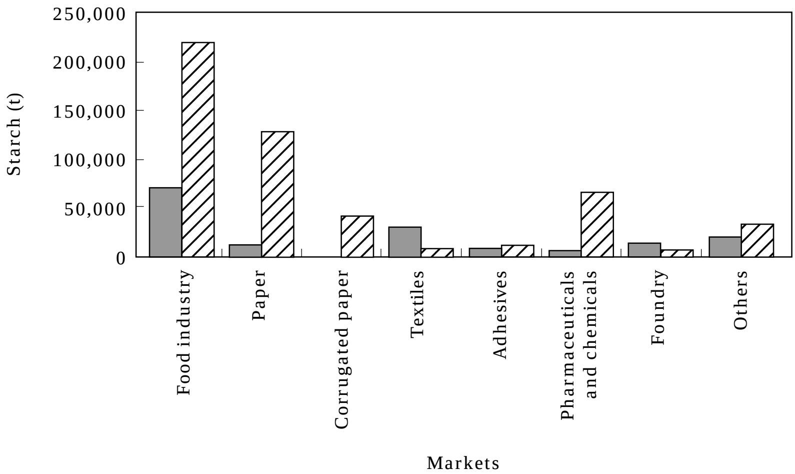

Figure 1. Starch markets in France, 1954-1987 (■ = 1954; ▨ = 1987). Nonfood uses in 1954 comprised 52% of starch production, which totalled 145,000 t; in 1987, 58% of 710,000 t.
Note: "Others" include such markets as drilling muds, flocculation agents, building materials, and mining.

Before the 19th century

Only wheat starch was produced in France, principally for starching fabrics, powdering wigs, and gluing papyrus or paper, that is, exclusively nonfood uses. The convergence of glucose production, and that of beet sugar, with the industrial revolution of the 19th century, transformed this small-scale activity into a large industry, providing a wide range of raw materials suited to a considerably broadened range of applications. The discovery of dextrins in the 1830s, then of linters in the 1890s, and, most significantly, modified starches in the 1940s gave rise to the industry of today.

1960s to 1980s

The approach adopted by the developing starch sector was "new and traditional products for new and traditional markets." For example, the market for starch products in France from 1954 to 1987 (Figure 1) was characterized by:

(1) An almost five-fold increase in starch utilization. The annual growth rate in the last decade of starch utilization in the European Community (now the European Union) remained above 3.8%;
(2) A steadily increasing quantity of starch (from 52% to 58%) is destined for nonfood uses;
(3) A profound change in user markets: increased use by paper industries, and pure chemistry and pharmaceutical sectors, with a reduced use in the textile industry.

To confront these developments, the starch industry has had to adapt completely its product range, creating new products and seeking new applications. The industry has learned how best to add value to, adapt, or modify the functional and physicochemical properties of starches (e.g., viscosity, capacities for binding, thickening, adhesion, flocculation, and dispersion). A matrix of product versus market, and new versus traditional can be observed:

	Traditional products	New products
Traditional markets	Native and modified starches: *Food* *Paper* *Textiles*	Cationic starch: *Paper* Borated dextrins: *Adhesives*
New markets	Native starch: *Corrugated paper, ceiling tiles, wall panels* Pregelatinized starch: *Flocculation agents* Crosslinked, stabilized starches: *Frozen and microwave foods*	Isoglucose: *Beverages* CM starch: *Pharmaceuticals* Lipophilic starches: *Beverage emulsions, encapsulation* Organic acids, AA, enzymes

Approach adopted by the French starch industry during the 1960s to 1980s.

From the above matrix, the following points are worth noting:

(1) *Traditional markets for new products:* The development of cationic starches with increased retention capacity has considerably strengthened existing markets in the paper industry.

(2) *Traditional products in new markets:* The food marketing sector has largely evolved during the last few years, opening new markets for such modified starches as:

   (a) Pregelatinized starches, cold-soluble starches; reticulated starches (more stable under cooking conditions, in the preparation of ready-to-use foods);

   (b) Oxidized starches, resistant to retrogradation, for frozen products;

   (c) Reticulated and stabilized starches which prevent undesirable effects associated with certain modes of cooking (e.g., heating by microwave causes phase separations, varying degrees of swelling, breakage of the crust, and nonuniformity of flavors and aromas).

(3) *New markets for new products:* The development of isoglucose has opened up large markets, especially in the U.S. drinks industry. Likewise, fermentation techniques using starch as a substrate have opened up chemical, pharmaceutical, and other markets, providing a wealth of derived products.

For the next decade

The starch industry is now following a similar approach to strengthen and diversify its markets for the next decade:

	Traditional products	New products
Traditional markets	Native and modified starches: *Food* *Paper* *Textiles*	Fat and sweetner substitutes: *Paper (retention rate)* *Low calorie foods*
New markets	Starch, pregelatinized starch: *Biodegradable plastics* Carboxylic starches, surfactants: *Thermoplastic starches* *Detergents*	PHB/V, Polylactic acid: *Biopolymers* Bioconversions Cyclodextrins

Approach adopted by the French starch industry for the next decade.

Responding to future demands

This approach enables the starch sector to respond to emerging demands from existing or potential users such as nutritional considerations, quality requirements, or environmental concerns.

The Cassava Industry in Brazil

Traditionally, cassava is consumed as fresh roots, or processed into *farinha*, *polvilho azedo*, or starch for food, paper, and textile industries. Although *farinha* remains the principal market for cassava, the Brazilian cassava industry has taken a series of initiatives to diversify markets:

(1) *New markets for traditional products:* A new market for *polvilho azedo* (sour starch), a naturally fermented starch with bread-making properties, is developing urban fast-food outlets; and for *farinha* in mining.
(2) *New products for traditional markets:* In particular, the food industry is increasing its use of native or modified cassava starches, such as cationic starch and maltodextrins. Frozen cassava chips is another new product.

These new products and applications depend on previously well-identified target markets: the Brazilian cassava industries still have not moved toward *new* products for *new* markets. This is highly risky in terms of research and development, whether generating new technologies or identifying new markets and marketing strategies, particularly as these industries lack the necessary human and financial resources.

The French starch sector, to develop as described above, devotes more than 2% of its turnover to research and development—impossible to imagine in the current Brazilian context.

In an attempt to overcome this lack of resources, the Centro Raizes Tropicais (CERAT), together with the Universidade Estadual Paulista (UNESP), brought together about 50 researchers from several Brazilian research institutions and development-support institutions, to help the industrial sector follow the “new products for new markets” approach, along the lines of the following matrix:

	Traditional products	New products
Traditional markets	Quality and new cassava varieties: *Fresh consumption* Farinha Polvilho azedo Starch: *Food, paper, textiles*	High-fiber biscuits Fat substitutes: *Meat products, ice-creams* Cyclodextrins
New markets	Farinha, native starch: *Grits substitutes in beer brewing* Polvilho azedo: *Premixes for food industry*	Glucose syrups: *Food industry* Maltose syrups (MFT): *Brewing, acid-fermented drinks, polysaccharides, packaging, uses of byproducts*

Brazilian cassava industry: present and potential future products and markets.

The research initiated under project EU-STD3 (value-added products, byproducts, and waste products of small and medium-scale cassava primary processing industries in Latin America) falls within the scope of this initiative, particularly in terms of new products for new markets.

Some of these research efforts will transfer to the industrial world of secondary processing (e.g., use of *farinha* or cassava starch in beer brewing as a substitute for maize grits, formulation of sour starch-based premixes for production of, for example, *pão de queijo*). The business community has already expressed interest—an indication of the relevance of the approach adopted.

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CHAPTER 35

EXTRUSION PROCESSING OF CASSAVA: FORMULATION OF SNACKS

N. Badrie and *W. A. Mellowes**

Abstract

Acceptable snack-type extrudates were produced, using flour from cassava (*Manihot esculenta* Crantz) as the main ingredient. Various formulas of cassava flour blended with other ingredients were tested. Extrusion processing was carried out, using a laboratory extruder (Wenger X-5, single-screw) under constant conditions, where feed moisture was 11%, barrel temperature 120-125 °C, screw speed 520 rpm, and feed rate 250 g/min. Sensory attributes of color, flavor, and texture, and overall acceptability were rated by panelists on a 5-point scoring system. Analysis of variance indicated significant differences ($P < 0.01$) for sensory attributes and for formulas. Flavor scored the highest, reflecting the presence of popular spices in the blends. Formula F4 received the highest scores for flavor and color and for acceptability. All formulas were acceptable, except for F7 and F8, which contained yeast. Color was most attractive when 0.1% turmeric was added.

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Introduction

Cassava (*Manihot esculenta* Crantz) is grown mainly in tropical developing countries where it is a primary source of carbohydrates for millions of people (Coursey, 1978; Nestel, 1973). The roots do not store well after harvest and usually begin to deteriorate within 2 to 4 days (Odigboh, 1983). Processing helps solve the storage problem (Sammy, 1971) and increases the usefulness of cassava.

Snack foods now comprise an important part of the daily nutrient and calorie intake of many consumers. They can be sweet or savory, light or substantial, and may even be endowed with attributes such as "healthy" or "just for fun" (Tettweiler, 1991). Among West Indians, spicy snacks are especially popular.

Extrusion processing is one of the fastest growing, and most important, food-processing operations of recent years (Harper, 1981a; Paton and Spratt, 1984). The food industry has invested considerable research in the extrusion processing of a wide range of foodstuffs, developing many successful products (Linko et al., 1981), including snacks, baby foods, cereals and starches, and/or vegetable proteins (Harper, 1981b).

Cooked, extruded snacks are generally prepared from cereals such as de-germinated maize meal, and rice and wheat flour (Smith, 1976).

In Trinidad and Tobago, maize meal is a major imported ingredient for extruded foods such as ready-to-eat snacks. Limited work has been done on the extrusion of cassava, resulting in the absence of cassava extrudates on the local market. The objectives of this research were to (1) use cassava flour as the main ingredient for a snack product under suitable processing conditions, and (2) determine, by sensory evaluation, the acceptability of extrudates of various formulas.

Materials and Methods

Feed ingredients

Cassava roots of the local variety 'Maracas Blackstick' were processed into flour (Figure 1) within 48 hours of harvesting. The flour was then blended with small amounts of additional ingredients to yield a variety of formulas. These ingredients were powdered spices, such as onion (0.2%, 0.5% w/w), garlic (0.2%, 0.5%), chili (0.2%, 0.5%), turmeric (0.1%, 0.2%, 0.5%, and 1.0%), and paprika (0.2%, 0.5%); sucrose (0.5%); uniodized salt (1.0%, 1.5%); monosodium glutamate (MSG, 1.0%), dried skimmed milk (0.5%); soybean oil (4.0%); yeast (1.0%, 1.5%), and defatted soybean flour (5.0%, 10.0%).

The feed sample of each formula was left to equilibrate for 24 h and adjusted to the targeted feed moisture of 11% d.b. The samples were again left to equilibrate at 4 °C for 24 h and, before extrusion, were allowed to reach ambient temperature. After cooking, the extrudates were packed in high-density polyethylene (HDPE) bags and stored at 4 °C in sealed

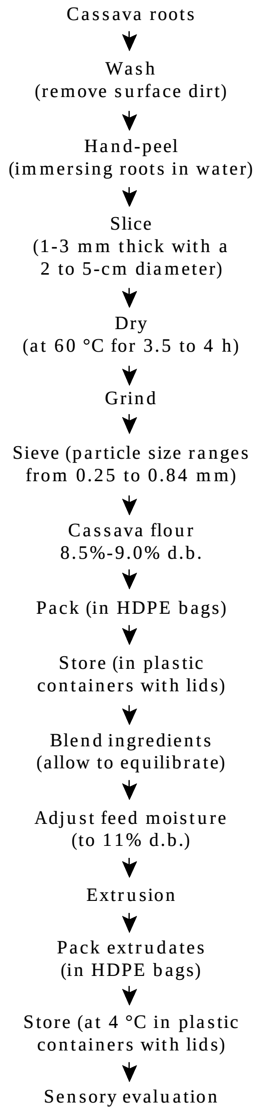

Figure 1. Procedures for extruding cassava flour blends. (HDPE = high-density polyethylene.)

plastic containers. Extrudates were presented to panelists for sensory evaluation within 2 days of extrusion.

A single-screw laboratory extruder, with a 2.5-cm diameter, was used (Wenger X-5, Wenger Manufacturing Company, Sabetha, Kansas). The screw was of decreasing pitch with a compression ratio (channel depth in feed zone to channel depth in metering zone) of 2:1 and length to diameter (L/D) ratio of 15:1. The die diameter was 5.0 mm and land length 9.0 mm. The die plate was attached to a breaker plate, 6.0 mm thick. The extruder consisted of eight stainless steel, jacketed head sections. Each section in the barrel was uniformly supplied with steam generated from a Sussman Electric Boiler (Hot-Shot Model, MB-6, Automatic Steam Corporation, NY). Barrel temperature was monitored by thermocouples mounted inside the barrel, using a temperature recorder (Type BD41, Kipp and Zonen, Holland). A feed hopper with paddle agitator ensured uniform feed flow into the extruder barrel.

Extrusion conditions

Badrie and Mellowes (1991b) had already established suitable extrusion conditions for cassava flour: blends should be extruded at constant conditions of feed moisture 11% d.b., barrel temperature 120-125 °C, screw speed 520 rpm, and feed rate of 250 g/min.

Proximate analysis

The proximate composition of cassava flour and the crude protein (%) of defatted soybean flour were determined by AOAC (1965) procedures, except for crude fiber (AACC, 1983). Total carbohydrate was determined by difference. Amylose was estimated with a rapid colorimetric method (Williams et al., 1970).

Sensory evaluation

Extrudates were evaluated by 10 panelists, who were students and faculty staff of the University of the West Indies. They were widely experienced in the sensory evaluation of food products. They rated the sensory attributes of color, flavor and texture, and overall acceptability according to a scale where 1 = unacceptable; 2 = poor; 3 = acceptable; 4 = good; and 5 = excellent. In addition, comments were required.

Extrudates of uniform size were served in sealed polyethylene bags, randomly coded by three digits. Two samples were presented per session and water was provided for rinsing between samples. Scores assigned to each quality attribute and to the formulas were subjected to analysis of variance to determine any significant differences. Sensory means were separated by Tukey’s test (Larmond, 1977). Sensory evaluation was conducted at the University’s Food Technology Laboratory, between 10:00 a.m. and 11:00 a.m.

Results and Discussion

Proximate composition

The proximate composition of cassava flour was crude protein, 1.5%-1.6%; crude fat, 0.6%-0.7%; crude fiber, 1.7%-1.8%; ash, 1.5%-1.7%; total carbohydrate, 85.2%-86.2%; and starch amylose, 16.4%. Crude protein of defatted soybean flour ranged from 52.1% to 52.2%. When 5% or 10% defatted soybean flour was added to cassava flour, the crude protein content rose from 1.38% ± 0.02% to 5.20% ± 0.03 or to 7.49% ± 0.05%, respectively.

Low protein (< 3%) staples such as cassava do not provide adequate protein for human requirements, even when ingestion exceeds caloric requirements. In contrast, diets with cereals (8%-10% protein) can meet adult protein requirements (Cheftel et al., 1985). Soya protein, rich in amino acid lysine (Harper, 1981b), can be used to fortify cassava flour.

Soybean flour was added to the cassava flour blend to increase the protein content, improve quality, and increase the yellow color of the extrudate. Badrie and Mellowes (1992b) found that soybean flour makes extrudates more attractive and yellower, resulting in a change of Munsell color notation from 4.62Y 6.38/1.75 to 5.04Y 6.46/2.19 at 5% soybean flour or to 5.30Y 6.46/3.10 at 10%. Thermal processing of food can increase the potential for interaction between lipids, proteins, carbohydrates, and their breakdown products (Bruechert et al., 1988). Maillard browning appeared the most likely reason for the color change.

Badrie and Mellowes (1992b) also found, however, that adding soybean flour reduced extrudate expansion and increased bulk density. Extrudate expansion was negatively correlated with crude protein ($P < 0.01$, $r = -0.88$).

Establishing processing conditions

Sensory attributes of extrudates depend on extrusion conditions and feed material. Badrie and Mellowes (1991b) established suitable processing conditions, evaluated on the bases of extruder performance and the physical and chemical properties of extrudates.

Optimal expansion (2.82) occurred at a feed moisture of 11% d.b.—the minimum moisture necessary to obtain a flow of the extrudate through the die (at 120-125 °C, screw speed 520 rpm, and feed rate 250 g/min). Lower feed moisture either blocked the rotation of the screw (there was no transition from the original floury nature to the 'melted' state typical of extrusion) or the extrudates emerged from the die in bursts. Only at 11% feed moisture was a more uniform moisture distribution and, thus, a more elastic dough achieved, resulting in a smooth surface texture. Foods with a lower moisture content also tend to be more viscous, the greater pressure differential resulting in better puffing.

The optimal expansion of cassava flour extrudate can be related to its microstructure. Scanning electron microscopy on cassava flour extrudates (Badrie and Mellowes, 1991a) at 11% feed moisture revealed wide porous air cells with thin cell walls. Extrudate expansion was positively correlated ($P < 0.05$, $r = 0.80$) to the water solubility index (WSI). At 11% moisture, the lowest texture values were recorded. Low-moisture extrusion, according to Harper (1989), can cause more mechanical damage (shear stress) to the feed, resulting in a softer texture. At 11% moisture, a more intense and attractive color (4.62Y 6.38/1.75) was also obtained.

Extrusion was stable between 100 and 125 °C, producing uniform, puffed products. Temperature increases from 100-105 °C to 120-125 °C brought corresponding increases in extrudate expansion. At higher temperatures (130-155 °C), extrudates became increasingly irregular, degenerating to rapidly ejected fragments. Temperatures above 125 °C probably resulted in a weakened structure and led to a rougher extrudate surface texture.

Establishing formulas

Because spicy snacks are a particular favorite of West Indians, powdered flavorings of onion, garlic, chili, paprika, and turmeric were included in the blends. Turmeric, a major ingredient of curry powder, also lent a more appealing yellow color. Other flavor enhancers were sucrose, salt, and monosodium glutamate. Dried skimmed milk provided both protein and flavor. Soybean oil was added at 4% level—a level at which Badrie and Mellowes (1992b) showed that lowest bulk density and highest extrudate expansion resulted, linked to increases in the WSI and total reducing sugars. Hsieh et al. (1990), working with maize meal extrudate produced by a twin-screw extruder, reported that adding salt and sugar enhanced radial and axial expansion but reduced bulk density and breaking strength.

For the first formula (F1), sensory scores for all parameters were better than acceptable, that is, higher than 3 (Table 1). But panelists' comments revealed that the color was unevenly distributed and too yellow. Extrudates were also too spicy and too salty, with a distinct taste of turmeric. Expansion was acceptable, but texture was slightly hard and the extrudate overly dense.

For the second formula, F2, adjustments were made to F1: the level of turmeric was reduced from 1% to 0.5%, and salt was reduced from 1.5% to 1.0%. Panelists again found the extrudates hard, too spicy, too yellow, and tasting of turmeric, although all sensory scores were acceptable (Table 1).

For formula F3, turmeric and paprika were reduced from 0.5% to 0.2%. A significantly better flavor and more acceptable color resulted (Table 1), but extrudates of F4 (0.1% turmeric and 1.5% spices) gained the highest overall acceptability, scoring highest in both color and flavor.

For F5, spice content was further reduced to 0.9%, but panelists found the extrudates too bland, and the flavor rating dropped from 4.25 (for F4) to 3.83.

To improve texture of the extrudates, the percentage of defatted soyflour was increased from 5% to

Table 1. Sensory attribute scoring of cassava flour blend extrudates.†

Formula	Color	Flavor	Texture	Overall acceptability‡	Overall mean for formula
F1	3.18 bcdef	3.20 ef	3.42 abcd	3.24 bcdef	3.26 bcdef
F2	3.23 bcde	3.27 e	3.43 abc	3.30 bcde	3.37 bcde
F3	3.50 abc	3.92 ab	3.45 abc	3.59 ab	3.62 ab
F4	3.69 a	4.25 a	3.40 abcd	3.82 a	3.79 a
F5	3.58 ab	3.83 bcd	3.42 abcd	3.57 abc	3.60 abc
F6	3.48 abcd	3.81 bc	3.50 abc	3.55 abcd	3.59 abcd
F7	2.85 efg	2.91 efg	2.10 e	2.60 g	2.62 g
F8	2.95 efg	3.07 efg	2.67 e	2.88 efg	2.89 efg
Overall mean of attribute§	3.31 a	3.53 ab	3.17 abc	3.32 bc	

† *Columns:* scores followed by the same letter are not significantly different among formulas at $P < 0.05$. *Rows:* values of overall mean attribute followed by the same letter are not significantly different among attributes $P < 0.05$.
LSD of formulas = 0.43; *LSD of attribute* = 0.25.

‡ On a scale where 1 = unacceptable, 3 = acceptable, and 5 = excellent.

§ Mean of 10 replications.

10% (F6), thereby reducing the total carbohydrate level. The result was a reduced extrudate expansion and an increased bulk density, but no significant change in texture. Adding cassava starch to cassava flour (i.e., increasing the total carbohydrate) tended to increase all textural attributes, the extrudate becoming less elastic or springy (Badrie and Mellowes, 1992b).

Badrie and Mellowes (1992b) showed that when soybean flour was added to cassava flour, the percentage of noncarbohydrate components (in particular, crude protein) increased. Extrudate expansion was negatively correlated with crude protein ($r = -0.88$, $P < 0.01$). Bulk density was negatively correlated ($r = -0.96$, $P < 0.05$) to extrudate expansion and positively correlated to crude protein ($r = 0.89$).

To reduce the bulk density of the extrudates, instant dry yeast was incorporated in the blend at 1.0% (F7) and 1.5% (F8). However, these additions resulted in unacceptable sensory scores. The effectiveness of sodium bicarbonate (baking powder) or maize amylose on reducing extrudate bulk density will be assessed in a later study. Although amylose tends to provide surface regularity and lightness, cassava starch or flour has too low an amylose content (16.4%) and produces denser, less radially expanded extrudates (Badrie and Mellowes, 1992a).

Sensory scores

Analysis of variance indicated significant differences at both 5% and 1% level for sensory attributes and formulas (Table 2).

Table 2. Analysis of variance of sensory scores for cassava flour blend extrudates.

Source of variation	df	*MS*	*F*
Attributes	3	0.18	5.63**
Formulas	7	0.65	20.31**
Error	21	0.032	
Total	31		

** Significant at $P < 0.01$.

Flavor received the highest overall mean score (3.53, i.e., better than acceptable), with texture (3.17) registering the lowest, although also better than acceptable. Only F7 and F8 proved unacceptable (Table 1). Panelists commented on the unique flavor of cassava extrudates. However, they tended to rate texture lower because of their tendency to compare cassava extrudates with the popular maize extrudates. Cereals have excellent expansive properties and are well suited to thermal extrusion.

As Stanley (1986) observed, texture is the major obstacle in remodelling ingredients into acceptable foods. To produce products in the highly acceptable or excellent categories, panelists recommended lightening texture and reducing bulk density and surface irregularity of extrudates.

The F4 overall rating of 3.79 was significantly ($P < 0.05$) higher than other formulas.

Conclusions

Distinctive and acceptable extrudates can be produced, using cassava flour as the main ingredient. The study pointed to texture, bulk density, and surface regularity as areas requiring attention. Flavor achieved the highest overall rating, attributable to the 1.5% spice in most formulas.

Except for F7 and F8, to which dry yeast had been added, all formulas were acceptable. Formula F4 emerged as the best overall product, having scored the highest for flavor and color. Color was found to be most attractive when 0.1% turmeric was added.

Other formulas, especially those incorporating local ingredients, can be tried. Successful development of extruded cassava products for the snack food industry in the West Indies could give rise to competition with popular, established maize-based products, the meal for which must be imported. Extrusion is a rapidly growing food-processing operation and extruded spicy snacks are popular in the West Indies, but more trials and consumer-type sensory evaluations are necessary before cassava-based extruded snacks can enter the local market.

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CHAPTER 36

THAI CASSAVA FLOUR AND STARCH INDUSTRIES FOR FOOD USES: RESEARCH AND DEVELOPMENT[1]

*Saipin Maneepun**

Introduction

Cassava has become a major cash crop for Thailand: in 1993, production was about 21 million tons, and increasing (TDRI, 1992). About 90% of total production is exported, mainly to Europe. Although cassava is mostly processed into pellets and chips for animal feed, the volume of these products has decreased slightly during the last decade in favor of cassava flour and starch for domestic industry and export (Table 1).

In 1990/1991, although 96 cassava starch processing factories were registered, only 55 were operating. Total production capacity was 1.5-1.8 million tons, of which 50% was for export, 25% for food-processing, and 25% for nonfood industries.

In 1991, the 55 cassava starch factories could be classified into 46 starch factories and 9 modified-starch factories. Monosodium glutamate (MSG) processing ranks highest among those cassava starch processing industries manufacturing amino acids (Table 2; Rodsri, 1993).

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1. No abstract was provided by the author.

Recently, lysine has become available and is used as a nutrient in feed mills. At present, the Thai Government is planning to support research that would help diversify the use of cassava starch in various industries to prevent falling prices. Cassava starch industries only produce 50%-70% of their total capacity, and thus have potential for further development.

Production and Development of Cassava Flour

Two kinds of cassava flour-processing factories operate in eastern Thailand: traditional and modern.

Traditional factories

Flour-processing factories were first built in the early history of cassava production in Thailand. The model of operation—a family business that employs now-obsolete technology—is still common in some parts of Thailand. Cassava roots are first crushed, then soaked in water. The resulting starch is extracted, sun dried, and pulverized into flour, which, however, is inferior in quality and bulk. It is used for making such products as noodles, desserts, and sago, most of which are sold on local markets.

Table 1. Export of cassava sago, chips, pellets, and starch from Thailand, 1982-1991, in metric tons.

Year	Sago	Chips	Pellets	Starch	Total prod. (x 1000)
1982	2,397	523,059	6,892,786	396,754	17,788
1983	2,948	279,913	4,554,332	359,298	18,989
1984	5,831	137,808	5,975,136	449,183	19,985
1985	7,566	123,702	6,474,503	482,309	19,263
1986	5,243	35,699	5,842,468	435,154	15,255
1987	7,420	72,833	5,777,137	353,594	19,554
1988	6,663	312,460	7,334,446	452,199	22,307
1989	9,223	130,201	9,185,466	501,329	24,264
1990	8,447	210,814	7,316,368	531,365	20,701
1991	10,060	113,205	6,269,458	549,022	19,705

SOURCE: Rodsri, 1993.

Table 2. Use of cassava starch in Thailand.

Uses	Percentage of total use
Direct consumption	26
Industry:	
Monosodium glutamate	19
Glucose syrup	15
Paper	9
Food	7
Sago	6
Textiles	2
Timber	1
Other	15
Total	100

SOURCE: Rodsri, 1993.

Modern factories

Many flour-processing factories have been modernized since World War II to produce high-quality cassava flour for export and use in domestic industry. The role of cassava thus changed from being a local crop for domestic consumption to a major commercial crop for export. At present, modern processing equipment is being developed for export to neighboring countries such as China, Vietnam, and Indonesia. The capacity of such equipment ranges from 50 to 100 t/day (Figure 1). In modern processing:

(1) Cassava roots are weighed and measured for their starch content.
(2) The roots are precleaned by a soil separator, then passed through a cleaning machine and peeler. Peeling makes extracting starch easier.
(3) The roots are then crushed and liquid starch is extracted, leaving a cake, which is sun dried before being used as a supplementary feed or for producing cassava chips and pellets.
(4) The liquid starch is purified by passing it through a sulfur vapor to rid the starch of sap.
(5) Water is then filtered out and the starch dried mechanically. It is then packed and shipped to markets.

On the average, 1 kg of fresh roots yields 200 g of starch and between 40 and 90 g of cake. Cassava flour quality depends on the manufacturing process. If the process is efficient and clean, the flour will be of high quality. Quality is judged by granule size; flour color, smell, and purity; fiber and ash contents of flour; humidity, acidity, and viscosity of liquid starch; and cake. At present, a cassava breeding program has been established to develop varieties that have high starch content: 22%-24%, depending on the growing season.

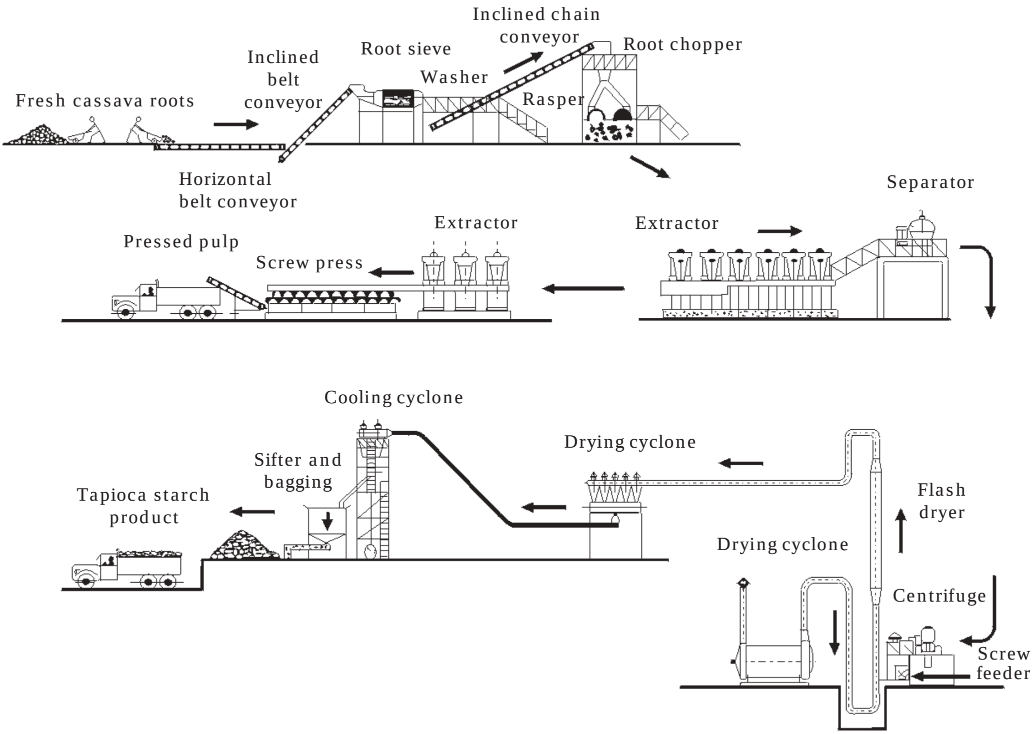

Figure 1. Processing tapioca starch, Thailand. (From Thai Tapioca Starch Industries Trade Association, 1976, personal communication.

Standard Specifications for Starch for Export and Local Markets

The Ministry of Commerce has established specifications for inspecting and controlling cassava flour and starch for export.

Certified products must be inspected according to Ministry standards and/or importer specifications. "Cassava flour/starch" is defined as that "obtained from cassava root [as] a white or cream-colored powder that does not include modified starch." Cassava flour and starch are graded at three levels, each with its own specifications (Table 3; Ministry of Commerce, 1993).

Standards for cassava flour and starch used locally were established in 1974 by the Thai Industrial Standard, Ministry of Industry: "Flour/starch obtained from cassava roots (*Manihot utilissima*) has starch granules of microscopic appearance, consisting of a cluster of two to eight granules, each granule measuring 5 to 35 µm and having an average diameter of 15 µm. Most starch granules are oval or truncated at one end to form a kettledrum shape while the other end has a cutting edge with the inner surface concave or irregularly flat. Starch granules clearly show an eccentric hilum with segment lines." The quality of local flour and starch is classified into three grades (Table 4; Ministry of Industry, 1978).

Table 3. Export standards for cassava flour and starch at three grades, Thailand, 1993.

Characteristics	Supreme grade	First grade	Second grade
Starch (day basis) (%)	85	83	80
Moisture content (%)	13	14	14
Ash (%)	0.2	0.3	0.5
Fiber (cm^3/50 g flour)	<0.2	<0.5	<1.0
pH	4.5-7.0	3.5-7.0	3.0-7.0
Particle size (mesh hole = 150 µm) (%)	99	97	95

SOURCE: Ministry of Commerce, 1993.

Table 4. Local standards for cassava flour and starch at three grades, Thailand, 1978.

Characteristics	Grade 1	Grade 2	Grade 3
Starch (dry basis) (%)	97.5	96.0	94.0
Moisture content (%)	13	14	14
Ash (%)	0.15	0.30	0.50
Ash (acid insoluble) (%)	0.05	0.10	0.15
Protein (%)	0.3	0.3	0.3
Fiber (cm^3/50 g flour)	0.2	0.5	1.0
pH	4.5-7.0	3.5-7.0	3.0-7.0
Particle size (mesh hole = 150 µm) (%)	1	3	5

SOURCE: Ministry of Industry, 1978.

Both bulk and retail packers can stamp the appropriate grade mark on packets for consumers' selection. Retail packs are for home cooking. Information on using composite flour (that includes cassava flour) in foodstuffs is readily available at local bookshops.

Various food products from rice, bean, and wheat flours can improve their texture by substituting with cassava flour or starch.

Because cassava flour and starch are mostly processed with water, they contain no hydrocyanic acid. The Thai Standard for Cassava/Flour Starch Committee does not accept the codex standard for edible cassava flour acceptable to African countries. The African Regional Standard permits cassava flour to contain 10 mg/kg of hydrocyanic acid (FAO and WHO, 1992).

Cassava Flour and Starch in Local Food Products

Studies on incorporating cassava flour into bakery goods for the local market require research on the eating habits of the population. Because consumers prefer wheat-based products, industries using cassava flour have developed products made from mixtures of cassava and wheat flours. Such composite flours impart a unique taste and texture to the products.

Sponge cake made with cassava flour

The effect of composite flour on the quality of sponge cake has been studied by Saencharoenrat (1990). He tested four kinds of wheat flour (chlorinated cake flour = CCF, unchlorinated cake flour, all-purpose flour, and bread flour) with different levels of cassava flour: 0%, 20%, 40%, 60%, 80%, and 100%. He found that, when the level of cassava flour substitution was increased, protein content, ash content, and damaged starch content decreased. Changes in moisture content and pH, however, depended on the kind of wheat flour. The gelatinization temperature of composite flours was in the same range as that of the type of wheat flour used, whereas peak viscosity in gel formation increased. Water absorption, dough stability, resistance to extension, and extensibility also decreased as the mixing tolerance index increased. Sponge cakes made with these composite flours were then evaluated.

Results showed that the different kinds of wheat flour and the levels of substitution affected several characteristics of cakes. Increased levels of substitution increased batter viscosity and specific volume of cake, but decreased specific gravity of batter and palatability of cakes. The kind of wheat flour used affected ease of cutting the cake (bread flour scored the highest), pH (lowest with CCF), and palatability (highest with CCF). Palatability scores agreed with total cake scores. The ideal composite flour was 40% cassava flour and 60% CCF, that is, no significant differences were found (at $P = 0.05$) in palatability between cakes made from composite flour and cakes from 100% wheat flour.

Cakes stored at room temperature could be kept for only 2 days, whereas refrigerated cakes lasted at least 7 days. Ease of cutting increased with storage time, and moisture content and palatability decreased.

Cookies made with cassava flour

Chananithithum (1986) found that the maximum substitution of cassava flour for wheat flour in baking cookies was 40%. Results showed that the spread was high, compared with that of wheat flour. Most tasters found the composite-flour cookies to be palatable.

Spread in composite-flour cookies can be markedly reduced by using an emulsifying agent. Patco-3 (50% sodium stearic lactylate and 50% calcium stearic lactylate) and BV-15 (commercial cookie improver), used at 0.5% (flour basis), produced a cookie with a spread factor not significantly different from that of cookies made with commercial cookie flour. Nor were its organoleptic properties significantly different from those of the commercial cookie.

The storage life of composite-flour cookies was not significantly different from that of wheat-flour cookies. Composite-flour cookies could keep an acceptable texture for about 3 months when stored in polythene bags, rigid plastic containers (polyvinyl chloride [PVC]), or tin boxes. The 40%-composite flour can reduce cookie prices by almost 2%, compared with wheat flour. The production of composite-flour cookies has been scaled up, using cassava flour as a raw material.

Where cookies were made with 15% full-fat soybean flour, cassava flour could substitute wheat flour by as much as 50% (Boonyasirikool et al., 1987). The product still has more than 10% protein. Palatability tests showed no significant difference between these two types of cookies. Using vanilla and cocoa flavors can enhance product quality and make it highly acceptable.

Chemically Modified Cassava Starch for Use in the Food Industry

Cassava starch is a typical root starch and is used in the production of foodstuffs and adhesives. Direct use of native cassava starch is more frequent in home cooking than in industry. Root starch granules, when cooked, swell more and are more fragile (i.e., they break down easily and thin out during stirring) than are cereal starch granules. The viscosity of these starch pastes can be determined by using a Brabender viscoamylograph. After stirring, tapioca starch shows the lowest viscosity (Figures 2 and 3). When certain chemicals are introduced, they cross-link within the granule, tighten up the molecular network, restrict granule swelling, and so stabilize the viscosity of starch pastes against breakdown by agitation. Various modified cassava starches have been developed and promoted for use in the food industry.

Cassava starch phosphate

Industries manufacturing transparent noodles, sauces, and custards have been encouraged to use cassava starch phosphate as a replacement for mung bean starch (Maneepun and Sirirojana, 1990) and as a thickening agent in sauces (Sirirojana, 1987) and custard spreads (Parvet, 1988).

Niyomvit et al. (1990) studied the use of premixed cassava starch phosphate and native cassava starch

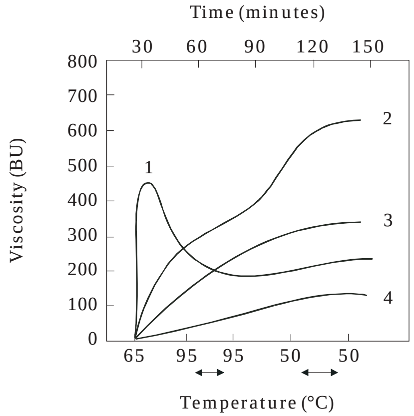

Figure 2. Amylograph of cassava starch, and cassava starch crosslinked with sodium tripolyphosphate and sodium sulfate at different times. 1 = cassava starch; 2 = cassava starch crosslinked with phosphate for 2 h; 3 = for 4 h; 4 = for 6 h. (From Sirirojana, 1987.)

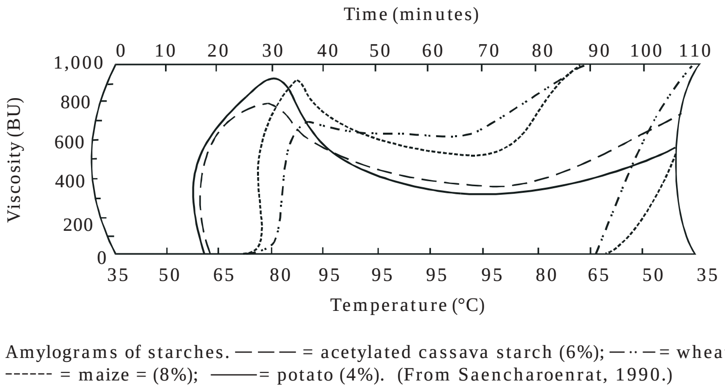

Figure 3. Amylograms of starches. — — — = acetylated cassava starch (6%); —·· — = wheat (9%); ------ = maize = (8%); ——— = potato (4%). (From Saencharoenrat, 1990.)

for the traditional Thai dessert, "kanom chen." Their experiments showed that the cassava starches changed their viscosity after cross-linking with the phosphate (Figure 2). Products were prepared for tasting panels, who determined that the premixed cassava starch phosphates, of 15% (2 h), 30% (4 h), or 15% (6 h), were highly acceptable. The characteristics required were transparency, easily separating layers, and stable texture. The Instron Food Tester showed that the texture was 60%-70% more stable than that of unmodified, mixed cassava starch.

Acetylated cassava starch (A starch)

Most countries permit the use of A starch as a direct food ingredient. The degree of substitution (DS) of starch acetate is determined by hydrolyzing with excess sodium hydroxide. The digestion of sodium hydroxide is almost equivalent to acetyl content (Institute of Food Research and Product Development [IFRPD], unpublished data). Amylograms showed that the peak viscosity and stability of acetylated cassava starch are comparable with those of starches from potato, maize, and wheat (Figure 3). The acetyl substitution lowered the rate of retrogradation of cooked pastes.

When cassava substituted 30%-50% of starches from mung bean, potato, or sweetpotato in the manufacture of jelly bean sticks, the resulting product was smooth, and had good texture, gloss, and flexibility.

Acetylated and slightly cross-linked cassava starch (A/C starch)

This is called acetylated di-starch phosphate and is usually cross-linked with phosphate. The DS of acetate can be determined by hydrolyzing a hot-water-soluble, acetylated di-starch phosphate with excess sodium hydroxide (IFRPD, 1993, unpublished data). The digestion of sodium hydroxide is almost equivalent to acetyl content.

Amylograms showed that the peak viscosity and stability of viscosity were higher in A/C starch than in potato, maize, or wheat starch (Figure 4). Swelling power is also greater in A/C starch than in wheat or maize starch but lower than in potato starch (Figure 5). The A/C starch is stable under conditions of freeze-thaw, high cold storage, and acidity. It has a short texture and high transparency. The product used depends on the viscosity of final products and is recommended for use in sauces made with vinegar or fruit juice. Because A/C starch has a good affinity with raw meat and is hard to retrograde, it can be used for boiled fish paste, deep-fried fish paste, fish ham, sausage ham, sausages, and meat balls.

Both A and A/C starches can be used for making wheat noodles (oriental type), resulting in smooth noodles whose texture when cooked is stable during cold storage.

Cassava starch ether (hydroxypropyl)

The cassava starch ether is used as a food ingredient in most countries. The degree of substitution of hydroxypropyl in starch ether is ascertained by hydrolyzing with hot sulfuric acid to propionaldehyde, which is then measured with a spectrophotometer after complexing with ninhydrin (IFRPD, 1993, unpublished data). Amylograms showed that cassava starch ether has a high peak viscosity and good stability, which means it can reduce retrogradation of cooked paste (Figure 6). This starch ether is being tried out in sauce-making (acid conditions).

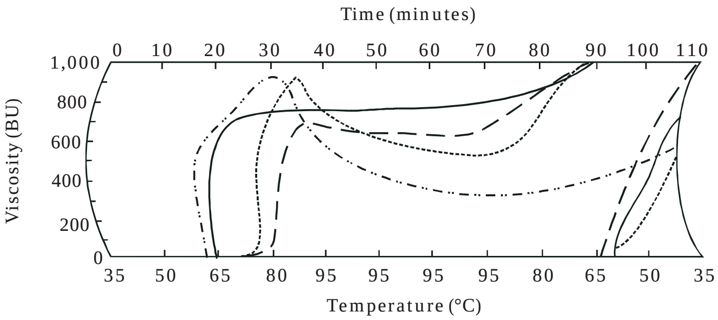

Figure 4. Amylograms of starches. ——— = acetylated and slightly crosslinked cassava starch (6%); — — = wheat (9%); ------ = maize (8%); —‥— = potato (4%). (From IFRPD Laboratory, 1993-1994, personal communication.)

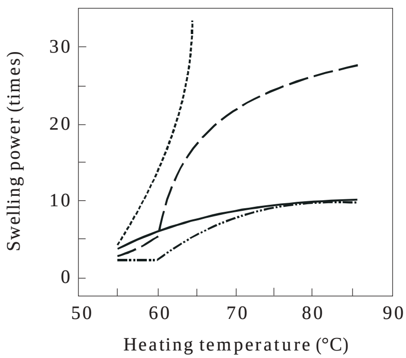

Figure 5. Swelling power of starches. — — = acetylated and slightly crosslinked cassava starch; ------ = potato; —‥— = wheat; ——— = maize. (From Saencharoenrat, 1990.)

One gram of starch and 49 g of water were mixed in a centrifuge tube. The tube was then heated at several temperatures, each fixed for 30 min, while the mixture was stirred. After heating, the mixture was centrifuged at 3,000 rpm for 20 min. The precipitate was then weighed. Swelling power was measured as the quantity of water 1 g of starch could absorb at a given temperature.

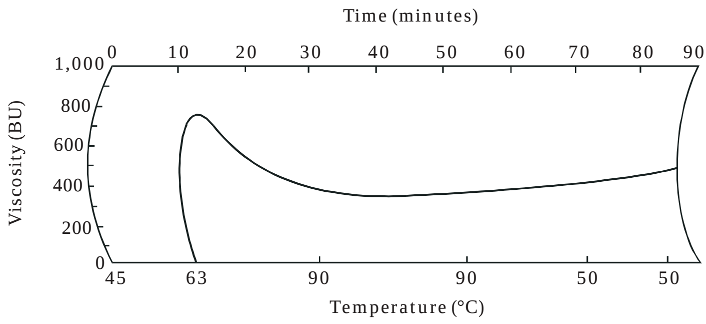

Figure 6. Amylogram of cassava starch ether (hydroxypropyl). (From IFRPD Laboratory, 1993-1994, personal communication.)

Standards for modified starch for the food industry

Standards were introduced to encourage cassava starch factories to produce modified cassava starch for the local market (Ministry of Industry, 1992). First published in January, 1992, these standards are upgrading modified-starch products as manufacturers apply for grade certification. The standards deal with different types of modified starch, physical and chemical additives used for modification, residues and limiting properties indicators, and methods of analysis.

Fifteen types of modified starches exist: pregelatinized starch, dextrin, thin boiling starch, alkaline treated starch, bleached starch, oxidized starch, di-starch phosphate, starch succinate, hydroxypropyl starch, starch acetate, monostarch phosphate, hydroxypropyl di-starch phosphate, acetylated di-starch adipate, acetylated di-starch phosphate, and combination chemical process starch.

Products of Chemical and Microbial Processing of Cassava Starch as Ingredients Used by Food Industries

Some industrial processes use cassava starch as raw material to manufacture final products that are themselves used as ingredients in foodstuffs. Such products are typically either seasonings or sweeteners. and have been developed locally and overseas. Most of the technology has been brought from developed countries with experts as consultants. Local institutions sometimes collaborate to promote further local development.

The processes are complex, involving chemical and microbial technologies that require sophisticated machinery. The final products are costly. Table 5 shows estimates of the cassava starch consumed by these industries (TDRI, 1992).

The seasoning industry

Thailand has three seasoning factories, one of which uses cassava starch and the other two molasses as

Table 5. Estimates of cassava starch use in seasoning and sweetening industries, Thailand, 1992.

Products	Cassava starch used (t/year)	Yield from 1 kg cassava starch (kg)
Seasoning industry:		
Monosodium glutamate and lysine (1991)	97,977	0.42
Sweetening industry:		
High fructose	15,000	1.00
Liquid glucose	30,000	0.90-0.95
Dextrose (monohydrous)	12,000	1.75
Dextrose (anhydrous)	100	0.50
Sorbitol	28,000	1.20

SOURCE: TDRI, 1992.

raw material for processing MSG. MSG and lysine products are expected to be in high demand in the future, especially from food-processing industries, for both local and export markets. Lysine processing, a new industry, has raised the consumption of cassava starch in the last few years. In manufacturing MSG, cassava starch is hydrolyzed by using α-amylase enzyme and α-amyloglucosidase to change starch into glucose. The fermentation is then continued with bacteria *Micrococcus glutamicus* or *Brevibacterium* spp., which are given urea as nutrient supplement. Eventually, crystalline MSG is formed. The process was first developed in Japan, imported to Thailand, and promoted within the local food industry.

The sweetening industry

Thailand first processed glucose syrup in 1950, glucose powder in 1976, and sorbitol in 1980. In 1989, the total sweetening industry consisted of seven factories: four producing glucose syrup, one producing sorbitol, and the remaining two, various sweetening products (Sathetkeingkai, 1989).

At present, the country's production of glucose syrup is about 76,000 t, which is sufficient for local needs. Considering the potential uses of glucose syrup, it could be used in the confectionery industry, which would add value to cassava starch by as much as 55%. The consumption of confectionery products is still low, and needs to be developed and promoted both locally and regionally.

Glucose syrup can be processed in various ways. At present, a continuous process is being developed to replace the batch process by using several types of reactors for starch digestion. This process, however, requires new equipment (such as a digestion tank, filter technique, and evaporator), which needs to be designed and developed.

Sweetening products also need to be developed and their use promoted in various food industries that manufacture, for example, soft drinks, beverages, ice creams, canned foods, and bakery products. Because of severe competition with the sugarcane industry, food-processing industries are slow to develop sweeteners from starches, including cassava starch.

Conclusions

Because cassava production is predicted to increase during the next decade, research and development are needed on cassava use, for both local and overseas markets. The Cassava Development Institute Foundation has been established to study the nature of the crop's production, use, and marketing. At present, cassava is still faced with falling prices, which affect growers, industries, and traders. Animal feed and nonfood products can also be developed as the market requires, thus adding value to the crop.

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Chapter 37

Yuca Rava and *Yuca* Porridge: The Functional Properties and Quality of Two Novel Cassava Food Products[1]

G. Padmaja, C. Balagopalan, S. N. Moorthy, and *V. P. Potty**

Introduction

Cassava (*Manihot esculenta* Crantz) is an important food staple for about 500 million people of the tropical world (Cock, 1985). Cassava roots are processed by several traditional methods, which vary widely from region to region. Usually, these techniques are intended to reduce the level of cyanogenic glucosides in the roots and improve palatability and shelf life of the resultant products (Cooke and Maduagwu, 1978). While fermented food products from cassava are popular in many African countries, preparations from dehydrated flour and those from cooked fresh roots are preferred in Asian and many Latin American countries.

Yuca rava and porridge are two novel food products made from cassava roots at the Central Tuber Crops Research Institute (CTCRI), Trivandrum, India. These products are likely to capture the Indian food market because of the ease and relative economy of their preparation (Balagopalan et al., 1988). Before being promoted in potential markets, these two products were evaluated for their quality, rheological and pasting behavior, and residual cyanogen contents. The results are reported in this paper.

Materials and Methods

Yuca rava and porridge were prepared (Figure 1) from three cassava varieties: the low-cyanogen cultivar H 1687; and two high-cyanogen cultivars, H 165 and H 226 (Table 1). Normally, varieties requiring less cooking are preferred for preparing *rava* and porridge as the starch in the roots does not gelatinize completely within the 10-min cooking time. This technique of partial gelatinization, or parboiling, helps in the partial swelling of starch granules. The dried, parboiled chips are powdered to obtain the finer fraction called "porridge" and the coarse fraction called *rava*.

Conventionally, *rava* is prepared from round cassava chips which are put into boiling water. An attempt was made to find out whether cyanogen retention in parboiled chips could be reduced with a smaller chip size. The round chips (1 cm thick) were either quartered to equal

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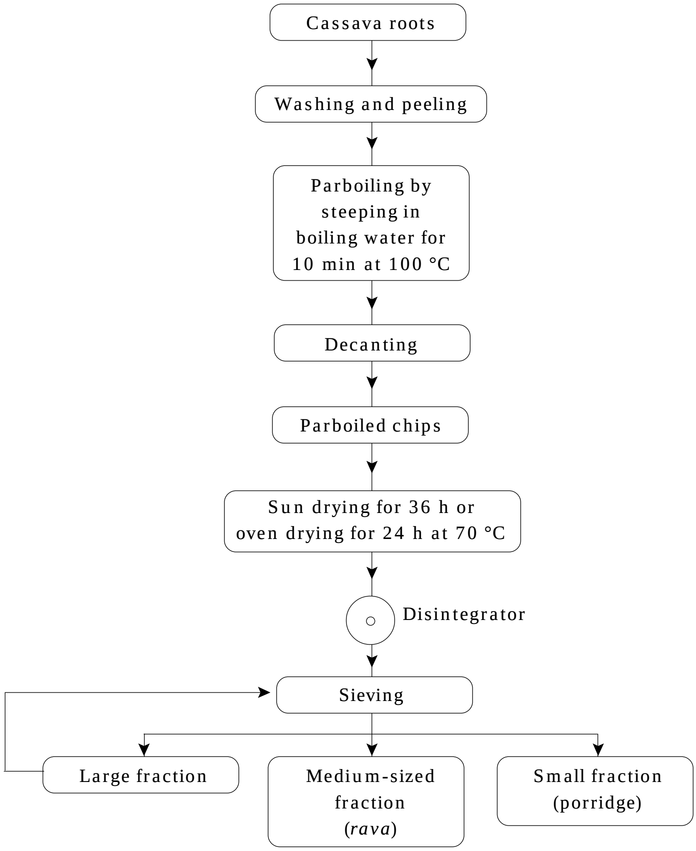

Figure 1. Manufacturing *rava* and porridge from cassava, India.

Table 1. Initial content of cyanogens (mg/kg DM) in cassava cultivars.

Cultivar	Cyanogens[a]		
	CG	NGC	FC
H 1687	88.97	37.27	31.21
H 165	271.15	45.67	31.25
H 226	214.12	26.81	20.98

a. CG = cyanogenic glucoside; NGC = nonglucosidic cyanogen (acetone cyanohydrin + free); FC = free cyanide.

portions or cut into strips of uniform width before being used to make *rava* and porridge.

A parallel study was undertaken to find out whether an initial presoaking of cassava chips for varying periods helps remove cyanogens from the roots. Round and quartered chips, as well as strips, were soaked for 30 min, 1 h, 2 h, or 3 h in standing water (1:4 w/v), then the water was drained off. *Rava* and porridge were prepared from these chips as normal.

The total and intermediate (nonglucosidic, i.e., acetone cyanohydrin, plus free) cyanogens, and free cyanide were quantified in the *rava* and porridge prepared from the three cultivars. The methods for extraction and initial stages of cyanogen determination up to the formation of cyanogen chloride were adopted from O'Brien et al. (1991). The coupling of cyanogen chloride was done with the barbituric acid pyridine reagents used in the Nambisan and Sundaresan (1984) procedure.

The viscographic behavior of *rava* and porridge samples from the three cultivars was studied with a Brabender viscoamylograph. A concentration of 10%-20% by weight of sample was studied at a heating rate of 1.5 °C per minute. The peak viscosity at 97 °C and viscosity after cooling were recorded. The swelling volumes were determined by standard procedure (Schoch, 1964). A sample of 400 mg *rava* or porridge was suspended in 40 ml water, heated to 95 °C, maintained at that temperature for 15 min, then cooled and centrifuged at 2,200 rpm for 15 min. The volume of the gelatinous precipitate obtained was taken as the swelling volume.

Starch and sugar contents of *rava* and porridge were determined by a standard titrimetric procedure (S. N. Moorthy, personal communication). Using 80% alcohol, sugars were extracted from samples by standing overnight. The remaining residue was hydrolyzed with 2N HCl to convert starch to sugars. These released sugars were quantified through ferricyanide titration (S. N. Moorthy, personal communication) and the starch value computed, using a factor of 0.9.

Results and Discussion

Of the cassava-consuming areas of the world, India is perhaps unique in making pregelatinized, dried preparations from cassava. *Yuca rava* and *yuca* porridge are two novel products that can be easily prepared, have an acceptable shelf life, and are tasty.

Cyanogen changes

The residual cyanogenic glucosides (CG) in *rava* made from the low-cyanogen cassava cultivar H 1687 ranged from 17.5-21 mg/kg DM and, in porridge, from 14.5-24.5 mg/kg DM, according to the type of chips (Table 2). These ranges were much lower than those for the products made from the two high-cyanogen cultivars, H 165 and H 226. The initial CG values were much lower for H 1687 roots (88.97 mg/kg DM), compared with the high-cyanogen cultivars (Table 1).

For each variety, however, the CG content among the three types of chips (round, quartered, and strips) did not vary significantly when they were put directly into boiling water, parboiled for 10 min, dried, and powdered to make *rava* and porridge (Table 2). The lack of variation may be a result of the rapid loss of linamarase activity at 100 °C as the roots were directly exposed to this temperature.

The extent of cyanogen removal during the boiling of cassava roots depends on boiling time, volume of water used, and size of root piece (Padmaja, 1993). Ezeala and Okoro (1986) reported that, after 35 min of boiling, cyanogens were undetectable in the roots they used. The initial cyanogen level of 218 mg/kg had dropped to 97 mg/kg within the first 5 min of boiling. However, the authors had gradually raised the chips to boiling point, taking 20-25 min. During that time linamarase could act on the glucosides.

Table 2. Cyanogen content (mg/kg DM)[a] of *rava* and porridge made from different types of cassava chips (round, quartered, and strips).

Cultivar Type of chips	*Rava*			Porridge		
	CG	NGC	FC	CG	NGC	FC
H 1687:						
Round	21.0	35.0	25.0	24.5	32.5	20.0
Quartered	19.0	36.0	22.5	21.5	39.5	17.5
Strips	17.5	26.5	17.5	14.5	25.5	19.0
H 165:						
Round	86.0	56.0	51.0	74.5	83.5	42.5
Quartered	95.5	46.0	32.0	90.5	56.5	37.5
Strips	108.0	40.5	21.5	100.5	48.5	27.0
H 226:						
Round	87.0	44.5	37.0	92.0	53.0	46.0
Quartered	70.0	67.0	47.0	82.5	41.5	30.0
Strips	111.0	31.0	27.5	115.0	24.5	21.0

a. CG = cyanogenic glucoside; NGC = nonglucosidic cyanogen (acetone cyanohydrin + free); FC = free cyanide.

Cooke and Maduagwu (1978) also observed that bound cyanogen was removed at a slower rate only during boiling and 55% of it was retained after 25 min of boiling. Nambisan and Sundaresan (1985) reported that during 30 min of boiling, only 45%-48% of total cyanogen was eliminated from the roots (varieties H 165, H 2304, and H 1678).

We found that the CG content dropped from about 89 to 17-21 mg/kg DM in the low-cyanogen cultivar H 1678 during 10 min of boiling. For the high-cyanogen cultivars, reductions were from 271 to 86-108 mg/kg in H 165, and from 214 to 87-111 mg/kg in H 226.

Fukuba et al. (1984) observed that cultivar variations strongly influenced cyanogen elimination in 1-cm diced roots during boiling or soaking treatments. They compared the effect of slow with rapid boiling. They found that, while 70% of total cyanogen was eliminated from cubes brought to boiling point, only 30%-35% of total cyanogen was eliminated if chips were put into boiling water, even after 10 min of cooking at 100 °C.

Soaking the different types of cassava chips for varying periods from 30 min to 3 h in standing water did not reduce the quantity of cyanogen compared with unsoaked roots (Table 3). Nor did chip type influence cyanogen elimination during soaking. Similar trends were obtained for low- and high-cyanogen cultivars. But cultivar variations are likely to affect the cyanogen elimination during soaking. Fukuba et al. (1984) obtained 54% elimination of total cyanogen from 1-cm diced roots of variety Bogor 397 during 10 min of soaking, while only 5%-6% cyanogen was eliminated from other varieties.

The reduction in CG during the preparation of *rava* and porridge indicates that cyanogen hydrolysis takes place during parboiling. The free cyanide contents of the *rava* and porridge obtained from each variety by various techniques vary

Table 3. Effect of soaking chips on cyanogen content (mg/kg DM)[a] of *rava* and porridge made from three cassava varieties, India.

Variety Type of chips	Hours	*Rava*			Porridge		
		CG	NGC	FC	CG	NGC	FC
H 1687 (low-cyanogen)							
Round:	0.5	24.5	32.5	23.0	25.3	34.8	24.3
	3.0	28.5	29.0	22.5	34.3	28.3	19.0
Quartered:	0.5	25.5	29.3	19.8	25.0	29.8	19.0
	3.0	32.5	25.0	19.3	32.0	30.8	19.8
Strips:	0.5	27.0	21.8	18.8	27.5	27.5	18.0
	3.0	24.0	25.0	18.8	23.0	25.3	17.5
H 165 (high-cyanogen)							
Round:	0.5	120.0	66.5	49.5	138.5	68.5	53.0
	3.0	116.5	93.0	67.5	108.5	90.5	77.0
Quartered:	0.5	147.5	63.0	51.0	110.5	56.6	49.5
	3.0	121.5	58.5	57.0	128.0	48.5	46.0
Strips:	0.5	160.5	67.5	56.0	133.0	60.5	43.0
	3.0	105.5	58.5	51.0	144.0	55.0	50.0
H 226 (high-cyanogen)							
Round:	0.5	78.0	37.0	17.0	128.0	30.0	19.5
	3.0	73.5	21.5	14.5	86.5	30.5	14.5
Quartered:	0.5	78.0	36.5	25.5	122.0	38.5	26.0
	3.0	70.0	29.0	19.0	98.5	51.5	40.0
Strips:	0.5	91.5	24.5	17.0	116.0	37.0	26.0
	3.0	100.5	21.5	13.5	99.0	39.0	31.0

a. CG = cyanogenic glucoside; NGC = nonglucosidic cyanogen (acetone cyanohydrin + free); FC = free cyanide.

little (Tables 1 to 3). This indicates that the free cyanide formed is rapidly lost from boiling water, but that a certain amount of free cyanide is retained in dried, parboiled chips.

Rapid parboiling, by adding chips to boiling water, is insufficient to eliminate cyanogen from high-cyanogen cultivars. Rigorous processing is needed to minimize cyanogen retention in high-cyanogen cultivars. But for low-cyanogen cultivars, such as H 1687, rapid parboiling helps reduce operational costs during manufacture of food products.

Rheological and swelling properties

Table 4 shows the rheology of *rava* and porridge samples of the three varieties. Significant differences in swelling volumes exist among the porridge samples of the three varieties. Swelling volumes were highest for porridge made from H 226 and lowest for that from H 1687. For *rava* samples, H 165

Table 4. Swelling volume and viscosity of *rava* and porridge made from cassava roots.

Cassava variety Type of chips	Swelling volume (ml/g)		Viscosity properties (BU)[a]			
	Rava	Porridge	Maximum viscosity		Viscosity breakdown	
			Rava	Porridge	*Rava*	Porridge
H 1687:						
Round	5.00	3.15	360	650	60	280
Quartered	5.00	3.05	350	700	70	350
Strips	5.35	3.75	320	600	30	190
H 165:						
Round	7.00	7.00	140	680	40	320
Quartered	6.20	6.25	160	820	20	400
Strips	6.25	5.75	150	800	30	360
H 226:						
Round	3.25	7.00	160	960	20	280
Quartered	3.25	7.50	220	900	30	350
Strips	3.75	7.25	180	870	35	190

a. BU = Brabender units.

had the highest values and H 226, the lowest.

No relationship was found between the shape of the chips used to prepare *rava* and porridge and swelling volume. The values obtained were much lower than those normally observed for corresponding starch samples which have 3-4 times the swelling volumes of *rava*. The lower swelling volumes can be attributed to the preliminary swelling of starch during parboiling of the chips. Most of the starch granules were already swollen during the *rava* preparation.

The swelling volumes observed also indicate an almost equal starch distribution in both *rava* and porridge samples. No significant differences in swelling volumes exist according to soaking period of chips, which was expected. Raja and Mathew (1986) observed the sedimentation volume of powdered, parboiled chips to increase slightly with longer boiling time. But we observed swelling volume to decrease with parboiling.

Viscosity data showed *rava* samples to have a different viscosity pattern to that of porridge samples. Porridge showed peak viscosity before 60 °C, whereas *rava* behaved like a starch, with a peak viscosity around 75-85 °C.

Recently, Raja and Ramakrishna (1990) found that parboiling affects viscosity properties. Earlier, Raja et al. (1982) reported that the viscosity of powdered, parboiled chips was lower compared with powdered, dried chips. This corroborates our findings.

Starch and sugar changes

No significant differences were observed in the starch content of *rava* and porridge samples according to cultivar. Starch content ranged from 52%-66% in the *rava* samples and 56%-70% in those of porridge. Neither was a relationship found between chip type and starch content of *rava* and porridge. Total sugar content was higher for the *rava* and porridge made from H 226 than from

Table 5. Starch and sugar changes (g/100 g DM) in *rava* and porridge made from cassava roots.

Cassava variety Type of chips	*Rava*		Porridge	
	Starch	Sugar	Starch	Sugar
H 1687:				
Round	66.18	14.60	64.38	15.74
Quartered	60.18	13.79	63.38	11.36
Strips	55.21	19.84	53.57	16.95
H 165:				
Round	64.29	13.61	70.31	11.90
Quartered	60.00	12.20	59.60	14.71
Strips	64.29	11.76	62.50	9.09
H 226:				
Round	67.67	14.81	56.60	20.20
Quartered	52.33	21.05	56.25	17.54
Strips	55.56	20.83	59.21	20.41

H 1687, and lowest for those from H 165. These parameters did not seem to influence the rheological or swelling properties of these food products (Table 5).

Conclusions

The rheological and swelling properties of the *rava* and porridge fractions made from the three cassava cultivars suggest their suitability as a wheat substitute for breakfast recipes and certain south Indian sweet dishes. However, the retention of cyanogens were found to be slightly high in the case of the high-cyanogen cultivars. We expect to study detoxifying processes in an attempt to develop suitable processing technologies for high-cyanogen cultivars, thereby increasing demand for food products made from such cultivars.

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Session 7:

Integrated Projects

Chapter 38

Integrated Cassava Research and Development Projects in Colombia, Ecuador, and Brazil: An Overview of CIAT's Experiences

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Abstract

This paper discusses CIAT's 12-year experience in developing an integrated cassava research and development project (ICRDP) approach. The origin, justification, methodology, results, and lessons learned from this approach are presented, using a comparative analysis of CIAT's experiences in Colombia, Ecuador, and Brazil. The ICRDPs have been effective vehicles for CIAT's Cassava Program to interact with various national research, rural extension, and development institutions. Existing production, processing, and marketing technologies have been validated and adapted to specific regional conditions with the ICRDP framework. New technologies have been generated through the synergy of research and development that ICRDPs promote. Results have demonstrated to research and development institutions, donors, governments, and policy makers that cassava is a crop that can play an important role in achieving development goals. Through the integrated approach, traditional cassava markets have diversified and overall demand for cassava has increased. This has reduced price variability while increasing yields and, as a result, created incentives for adopting improved technologies. Poor farmers' incomes and employment opportunities have also improved through the promotion of small-scale, cassava-based, rural agroindustries with low opportunity costs, especially for landless producers.

Introduction

In 1973, when CIAT's Cassava Program first took shape, few strong agricultural research programs in Latin America focused on cassava. Research was well behind, relative to other crops, and emphasized mainly aspects of production (Pérez-Crespo, 1991). The Cassava Program researched germplasm development and agronomic practices from 1973 to 1982. Results during this period were encouraging, and clearly demonstrated the technical possibilities of significantly increasing cassava production.

But farmers had no special interest in adopting new cassava production technology to raise efficiency or productivity. With an increasing concentration of Latin America's population in urban

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centers, preferences shifted from cassava as a basic dietary staple to foodstuffs easier to transport, store, and exchange. Thus, increasing cassava's use in Latin America was dependent on developing new products that would use cassava in its fresh state or transform it to a storable or higher value product, and in developing new markets for these products (Lynam, 1978).

In 1979, CIAT took an innovative step by adding the Utilization Section to the Cassava Program, thus extending its responsibilities for crop research beyond the development and transfer of germplasm and agronomic practices. This move was similar to that of many earlier projects in numerous countries, especially in Southeast Asia, that aimed to exploit cassava's industrial potential by transforming it agroindustrially into meal, flour, starch, alcohol, or other derived products. In Latin America, relatively few of these projects met with the anticipated success: some, trying to improve production, ran into marketing problems; others, investing in processing plants, encountered problems with the raw material's price or availability.

Analysis of these projects highlighted the need for an integrated approach to cassava production, processing, and market development. Cassava development could not be expected unless all three areas were simultaneously addressed in an integrated fashion. Research and development activities needed to begin by identifying potential markets for cassava and its products. Once identified, then product development, processing, production, and commercialization should begin, to develop the market effectively.

The Utilization Section first concentrated on developing technology to conserve fresh cassava roots for human consumption and on drying technology for the animal feed industry. Research activities on sun-dried cassava chips at CIAT were started in an attempt to solve quality problems in dried cassava chips and pellets produced in Thailand and Indonesia and exported to the European Union for incorporation into animal feed concentrates. Through this work, CIAT gained considerable experience in the natural drying techniques used in Asian countries.

But this accumulated knowledge could not be applied to Latin American conditions immediately. A series of reviews had cast doubts on the Program's ability to reach farmers with the technologies generated, and so attain increased productivity. After a series of internal planning exercises focusing on specific social objectives, a new research and development framework was formulated for the Cassava Program. This included the need to be directly involved in cassava-based, rural development programs, as a sine qua non condition for the crop's development (Cock and Lynam, 1990).

At the time the Cassava Program was searching for Latin American partners and sites to test this approach, the Colombian Ministry of Agriculture, through the Integrated Rural Development (DRI) program, was pursuing CIAT's collaboration to solve problems related to increasing production and decreasing demand and prices for cassava in the North Coast, an extensive cassava-growing area of Colombia. The two entities developed a collaborative program. The experiences gained in this and similar projects in Asian countries over the last 12 years has allowed CIAT to develop the integrated cassava research and development project (ICRDP) methodology discussed in this paper.

The Importance of Cassava in Latin America

Latin America produces 21% of the world's cassava. According to the Food and Agriculture Organization (FAO, cited in CIAT, 1993), Brazil, Paraguay, and Colombia are responsible for 92% of cassava production in this region. The crop is generally produced in marginal, rainfed areas and is grown by small-scale farmers with limited access to land, inputs, and improved technology. In areas where cassava is grown extensively, farmers often have no alternative crops because of climate and soil limitations.

Marketing channels available to cassava growers are usually limited to one or two traditional markets per region for either fresh roots or processed products such as *farinha da mandioca* (toasted cassava flour) in Brazil. As societies urbanize, demand for processed products may remain stable or even increase, creating shortages and high prices. But the overall demand for cassava tends to decline, creating price fluctuations and increasing commercial risks. Lacking additional market opportunities for fresh cassava, farmers have no incentives to adopt improved production technologies.

Fortunately, cassava has several characteristics that allow it to compete as a multiple source of carbohydrates, especially compared with other root crops, on the basis of price, yield, nutritional value, quality, and availability. Root dry matter content in cassava is higher than in other root crops (35%-40%), giving optimal conversion rates of 2.5:1 or better. Over 85% of root dry matter consists of highly digestible starch. Cassava starch has agglutinant properties that make it suitable for pelleting in animal feeds, such as for shrimp or fish, replacing expensive artificial agglutinants (Cock and Lynam, 1990).

The disadvantages of using fresh cassava roots directly in products such as animal concentrates are their bulk, rapid perishability, low protein content, and the presence of cyanogens in all root tissues. These disadvantages can be overcome by simple processing techniques, such as chipping and natural drying. For example, sun drying eliminates most cyanogens from root tissues. Increasing cassava's price competitiveness with other carbohydrate sources, and differentiating the uses of its high quality carbohydrate structure and composition, help overcome its low protein content.

Linking small-scale cassava farmers to potential growth markets via new processing technology and new product development is an important option that can help meet several social policy objectives such as income generation among marginal farmers and landless poor (Lynam, 1987). But penetrating alternative markets needs competitive farm-level prices, investment in processing capacity and management, and a coordinated expansion in production, processing, and use.

The integrated project methodology, developed during the last 12 years, aims at coordinating changes in farming systems with changes in the marketing system, within the framework of multi-institutional integration.

Integrated Cassava Research and Development Projects (ICRDPs)

Definition

An ICRDP is defined as an intervention at institutional, technological, social, and organizational levels to link small-scale cassava farmers to new or improved growth markets. Thus, demand for production technology is stimulated with potential to improve small-scale farmer welfare.

Methodology

The ICRDP methodology has four stages. These must be phased sequentially to succeed (Figure 1).

Macroplanning. The overall economic situation of the country or region initially targeted for an ICRDP is analyzed. The potential demand for cassava and derived products, the crop's ability to compete with other products and markets, and the potential for cassava production in different regions are considered. Information gathered in this phase ensures that the correct target region and the most promising markets are selected.

Microplanning. Information is gathered to define market characteristics, production practices and constraints, availability of institutional support, existing farmer organizations, cassava processing technologies, and regional government development priorities. Then, the target area is selected for the pilot project.

Pilot phase. During this stage, available technologies can be entirely reworked and adapted to local conditions. The project's institutional and organizational framework is determined and serves as the intersection point for cassava production, processing, and product development research. Farmer organizations are included at this stage and become the project's permanent actors and decision makers. At the end of this stage, enough reliable information is available to test the assumptions made during planning. The commercial phase is then either justified or rejected.

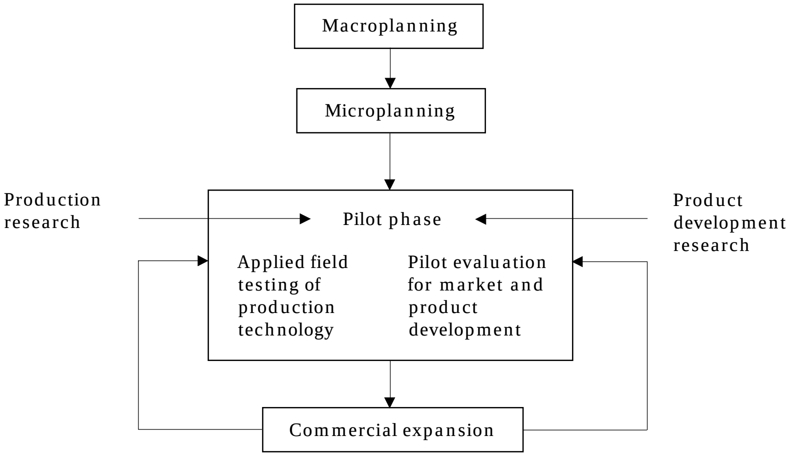

Figure 1. Planning integrated cassava research and development projects (ICRDPs).

Commercial expansion phase. The use of cassava processing technology and new or improved products can now be replicated or expanded, according to findings of the pilot phase. The new technology's commercial costs and the resources needed to promote its adoption on a wider scale can now be calculated. This includes credit lines for crop production, establishing processing capacity and operational capital, and institutional requirements to train and give technical assistance to farmers. At the start of the commercial phase, a monitoring system should be established, based on the information gathering mechanisms begun in the pilot stage. Finally, it must be remembered that the project framework is not a permanent mechanism per se and the end result of this stage should be a self-supporting, economically sustainable, cassava-based agroindustry.

Anticipated outcomes

The anticipated outcomes of the ICRDPs were:

(1) That national research, extension, and development agencies would become involved in a concerted effort to improve small-scale farmer welfare through activities focused on cassava;

(2) The development of cassava processing and product markets as income-generating activities;

(3) The creation of demand for improved cassava production technology.

Experiences and results

CIAT joined efforts with national counterpart agencies to initiate ICRDPs in nine Latin American countries (Table 1). These projects have included different products, markets, and processing technologies and have reached different stages of development.

In Mexico and Peru, the projects failed. The Mexican failure was caused by farmers not being committed and involved from the start and because the production, processing, and commercialization activities were insufficiently coordinated. The Peruvian project was economically nonviable because the target area was far from markets and another, more profitable, enterprise (cocaine processing) was competing.

In the Colombian, Ecuadorean, and Brazilian projects, the CIAT Cassava Program, through special funding, managed to have staff members directly involved in project implementation.

Table 1. Integrated cassava research and development projects in Latin America.

Country	Dried chips for animal feed	Flour		Starch		Fresh roots for human consumption	Leaves for animal feed
		Human consumption	Industrial use	Human consumption	Industrial use		
Argentina				Pilot			
Bolivia	Pilot						
Brazil	Commercial					Pilot	Pilot
Colombia	Commercial	Pilot		Pilot	Pilot	Commercial	
Ecuador	Commercial	Commercial	Commercial	Commercial	Commercial		
Mexico	Failed						
Panama	Commercial						
Paraguay	Pilot			Pilot		Pilot	
Peru						Failed	

The Colombian ICRDP

The North Coast is a major cassava production zone in Colombia. In 1990, it accounted for 52% of the nation's cassava production, representing 13% of total land under cultivation and 20% of the region's total value of agricultural production (Henry et al., 1994). According to Janssen (1986), 40% of the total small-scale farmer income from agricultural production in this area is derived from cassava cultivation. On-farm consumption and fresh cassava sold to urban markets have traditionally been the two main commercial outlets for the region's cassava crop, although some typical, processed, cassava-based products for human consumption also take a small share of the cassava market. Industrial uses of cassava have been virtually nonexistent in the region.

In the late 1970s, the DRI was already promoting cassava as an agricultural policy option in the North Coast. It provided credit and technical assistance to increase cassava production.

This traditional, production-oriented approach was relatively successful. Cassava production increased rapidly, mainly because of the effect that increased credit availability had on intensifying production by farmer beneficiaries of the DRI program. The rapid growth in production caused saturation in local markets, and prices dropped to such levels that farmers were unable to find buyers to recover their costs. To resolve this problem, the DRI program set up a postharvest committee, who contacted CIAT for help in finding alternative markets for the region's cassava production.

At the same time, CIAT's Cassava Program had already found that a large and expanding market for animal feed existed in Colombia, and was analyzing the possible use of dried cassava for this market. The two entities teamed up to assess the possibilities of entering this alternative market.

Of the various possibilities analyzed, the most promising seemed to be that of establishing cassava producer organizations to operate cassava drying plants and sell the dried cassava to animal feed factories. This approach appeared attractive for two reasons: first, the resource-poor farmers in the area could not individually afford to establish cassava processing infrastructures, whereas as an organization they could do so; and, second, the cassava drying process was proposed as a way to create an effective floor price for cassava roots, so that if prices in the fresh market were high, farmers could sell into these markets and make enough profit to pay off loans on the cassava drying plants. Roots unsuitable for the fresh market could be sold to the drying plants, allowing them to operate at a low level. Conversely, if the prices for cassava roots dropped, farmers could sell the roots to the drying plants and still make a profit.

To test this model's validity through a pilot project, the first cassava natural drying plant to be operated by farmers was established in Betulia, Department of Sucre, in 1981. The farmers were aided by CIAT who already had expertise in the cassava chipping and drying technology brought from Asia.

Despite their total lack of experience and tradition in cassava processing activities, the Colombian farmers quickly assimilated and adapted the technology. The initial promising results were used to formulate the project's expansion, which underwent two additional phases: the semicommercial (1981-1983), and the replication or commercial (1984 to date).

By 1991, about 150 cassava drying plants were operating in the North Coast (Figure 2), of which 105 were owned and operated by small-scale, cassava producers' associations and/or cooperatives. The remainder were exploited by private entrepreneurs who, during 1987-1991, were rapidly participating in the industry. The fast, widespread adoption of diverse types of cassava-drying in the region is now making accurate monitoring difficult (Henry, 1992).

During 1991, these 150 drying plants produced about 25,000 t of dried cassava chips, corresponding to 62,500 t of cassava roots—a demand representing 6.6% of total cassava produced in the region in 1991 and accounting for 5.7% of the total area planted to cassava. Project activities led to the rapid penetration of the Colombian animal feed market with dried cassava chips.

Throughout the project's span, cassava producers and processors received important institutional support, especially credit lines, technical assistance, and training. Important results were also obtained in the area of improved cassava production technology. The impact of the Colombian ICRDP can be best assessed by considering the added monetary value of dried cassava's annual production, foreign exchange savings from decreased cereal imports for animal feed, added employment opportunities generated in rural areas by expanding cassava production and processing activities, and enhanced links with goods sectors and services.

The Economics Section of CIAT's Cassava Program estimated that, from 1984-1991, the cassava sector in northern Colombia benefited by almost US$22 million (Gottret and Henry, 1994). These benefits resulted from integrating research to improve cassava crop management, processing, marketing, and consumer preferences in the framework of cassava-based, development projects with strong farmer participation.

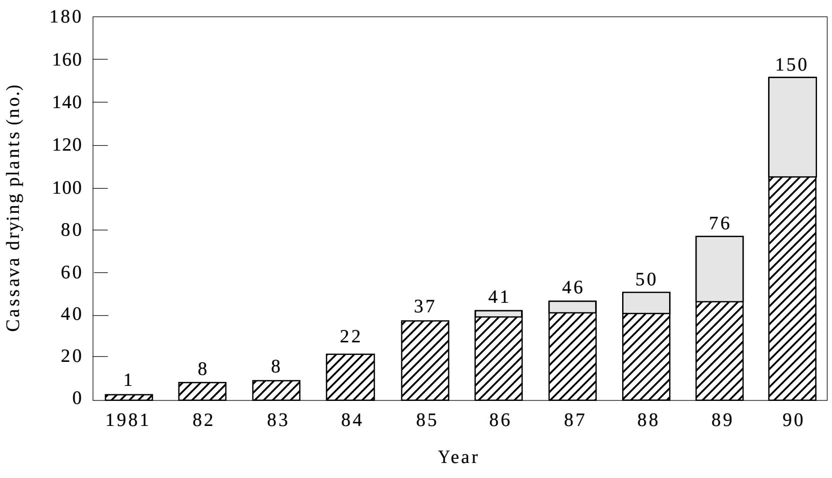

Figure 2. Adoption of cassava drying plants in Colombia, 1981-1990, by farmers' groups (▨) and private plants (□). (After Henry, 1992.)

Studies have also shown that adoption of cassava production technology components is significantly higher in areas with ICRDP activities than it is in areas not so influenced (Gottret and Henry, 1994). For example, 93% of cassava producers in areas with cassava drying activities and strong institutional presence adopted the cassava variety 'Venezolana' in 1991. But in areas not directly influenced by ICRDP activities, only 48% of cassava producers adopted it (Gottret and Henry, 1994).

The main lesson of the Colombian project was that farmers, when encouraged to participate in researching and solving their current problems and needs, become important partners for research-and-development institutions and make valuable contributions to identifying, adapting, and evaluating alternative solutions.

The Colombian project also validated an original hypothesis of the ICRDP model: that the integrated project approach, by creating new markets and better prices for cassava, will increase farmers' incentives to adopt improved production technologies.

Finally, the project demonstrated that small-scale farmer associations are indeed a viable mechanism or vehicle for technology diffusion.

The Ecuadorean ICRDP

From its beginning in 1985, the Ecuadorean ICRDP represented a challenge for CIAT in that the Colombian project, successful as it had been, demanded very high institutional costs, which had to be brought down. The project in Ecuador was therefore conceived as both a social and technical experiment, requiring specific institutional and organizational arrangements and allowing farmer organizations, extension workers, and national research and extension staff to play new roles (CIAT, 1992).

The project in Ecuador was implemented in a traditional, cassava-processing area of Manabí Province, a seasonally dry, coastal region, which accounts for 20%-30% of the national cassava production (MAG, 1990). In Manabí, family farming households have extracted cassava starch for over 100 years with little change in processing technology. The potential of cassava-drying technologies had been early identified as a viable alternative for promoting alternative uses and markets for the crop. But it was not until 1985 that conditions became economically favorable to launch the ICRDP in Manabí.

A favorable climate for cassava processing and sun drying, excess cassava production, and a predominance of small-farm population characterized the region as "optimal" for the project. Farmers were organized into small producer-processor associations called APPYs (Asociaciones de Productores y Procesadores de Yuca). From the start, these associations joined, as a second-order farmer organization, known as the Unión de Asociaciones de Productores y Procesadores de Yuca (UAPPY).

The UAPPY changed its legal status in 1992 to admit associations of rural workers (ATAPYs) and became the Unión de Asociaciones de Trabajadores Agrícolas, Productores y Procesadores de Yuca (UATAPPY). This change allowed small-scale farmers, lacking titles to their lands, and landless rural workers (such as women who could easily benefit from processing-generated jobs) to legally participate.

Begun as a marketing committee, the Union now includes 17 associations and performs a variety of functions including technical assistance, credit, marketing, accounting, training, product development, and monitoring. Farmers meet annually as stockholders to evaluate their progress and make recommendations to UATAPPY leaders and other project collaborators.

Colombian farmer-processors were brought to Ecuador to teach Manabí farmers the new chipping and drying technology. These farmer-to-farmer contacts were later reinforced by Manabí farmers visiting Colombia. They were able to see in action technical, organizational, and operational features of the Colombian cassava processing plants. From the start, farmer processors played an important role as promoters, technology transfer agents, teachers, and leaders of the project. Staff from local agencies and CIAT joined and supported farmers' efforts.

The basic chipping technology adopted was the same as that used in Colombia. Drying trays, a CIAT-suggested technology, were quickly adopted as an intermediate step toward building a cement drying floor. This allowed poorer farmer groups to get started quickly with fewer initial investment costs. Later, profits earned could be used to build the floor.

Project leaders and CIAT researchers assumed that the market for dried cassava in Ecuador would be the same as that in Colombia: the balanced feeds industry for poultry and livestock. Early in the project, serendipitously, it was discovered that cassava was an ideal substitute for imported chemical agglutinants for the feed pellets used by the Ecuadorean shrimp industry. The scale of this industry was such that demand for cassava flour could be more than 8,000 t/year.

Transforming dried cassava chips to flour for shrimp feed required new steps in processing because roots had to be peeled before drying. Peeling soon became an important source of added income for member and nonmember families, especially women, children, and elderly people, who usually had no other sources of income.

A different management system was also needed, in which the associations produced dried chips and sold them to the Union. The Union was obliged to develop milling capacity and management, using portable hammer mills to grind the dried chips into flour. This process catalyzed the idea of developing a Union-owned and administrated "Demonstration Center," where new cassava processing technologies could be designed, adapted, and tested, and training and demonstrations for farmers could be held.

In 1993, the Demonstration Center became the "Central Plant", reflecting its increasing roles in transformation, storage, and transshipment activities. Training and research activities were taken over, to some extent, by specific farmer associations, encouraging increased participation.

In 1989, the shrimp industry in Ecuador slumped: strong competition from Asian producers and problems with a shortage of larvae ponds cut shrimp production overnight, eliminating 95% of the demand for cassava flour. The Union reacted quickly, launching an all-out campaign to identify other markets. The Demonstration Center made it possible for farmers to rapidly adapt existing products for new markets.

For example, whole-root cassava flour was refined by passing it through a mechanical vibrating sifter, a process yielding a flour of the same granular size as wheat flour. This refined cassava flour began substituting wheat flour in fillers for resins used for making plywood, thus capturing an important share of this market. Bran, a byproduct from sifting, was also sold as a source of fiber to livestock feed industries.

In 1989, farmers, collaborating institutions, and CIAT learned a valuable lesson about the importance of diversifying products and markets. Since then, the Union's markets and products portfolio continued to diversify. Today, seven different primary products and four byproducts are produced and sold to seven different market sectors (Table 2), reaching more than 40 buyers.

The Ecuadorean cassava project's growth has been operational rather than in number of processing organizations. Initially fueled by strong market demand and reasonable funding for construction and operational credit, the processing associations' expansion was very rapid, from 2 in 1985 to 16 in 1988. By the end of 1988, a scarcity of donor funds for construction and a rapidly increasing inflation combined to make promoting the formation of new associations much more difficult for the Union. In 1992, there were 17 associations in Manabí, with a total of 320 members (Figure 3).

The Ecuadorean ICRDP differed from other ICRDPs by having the UATAPPY as agent of its members' growth and development. It has managed and often carried out project functions normally assigned to supporting state institutions or nongovernmental organizations (NGOs), including handling development funds. This has served to strengthen and promote

Table 2. Market sectors and products in the Ecuadorean cassava project, 1989-1992.

Market sectors	Products	Total annual output (t)				
		1988/89	1989/90	1990/91	1991/92	1992/93
Shrimp feed and exports to Colombia	White industrial flour		574	982	304	631
Shrimp feed[a]	Whole industrial flour	1,100	304	258	464	127
Plywood industry	Refined whole industrial flour			200	170	292
Ice-cream cone factories	Refined white food flour		33	6		33
Cardboard industry (Ecuador and Colombia)	Industrial starch		70	188[b]	57[b]	256[b]
Bakeries, traditional and large-scale	Food starch	5	10	6[b]	9[b]	17
Livestock feed	Starch bagasse and flour bran		24	103	29	166[b]
Total		1,105	1,015	1,743	1,033	1,522

a. After 1990/91, most of the "whole industrial flour" was used for other livestock feeds, and not shrimp pellets.

b. Includes starches or "bagasse" purchased by the Unión de Asociaciones de Trabajadores Agrícolas, Productores y Procesadores de Yuca (UATAPPY) from private starch processors.

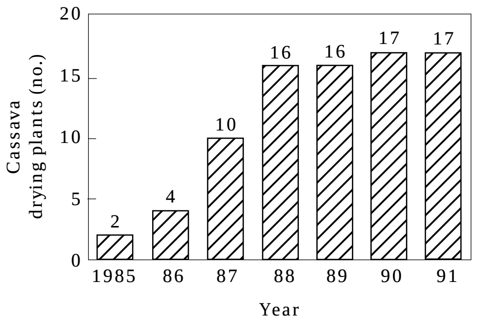

Figure 3. Expansion of cassava-drying agroindustries in Ecuador, 1985-1991.

sustainability of the project after state institutions and NGOs withdrew their support as funds run out.

Another difference has been the direct and active participation of women from the start in the Union and in all project activities, as producers, processors, and managers. Today, three kinds of processing associations exist: only men, only women, and mixed. Women comprise nearly 33% of total membership.

The UATAPPY experience with the integrated cassava project over the past years has fully validated three guiding principles that can be considered as part of the culture of the project's participants and the criteria for their collaborating well:

(1) The transfer of technologies is more rapid, efficient, and effective when end-users are directly involved and responsible.

(2) Farmers' organizations are effective intermediaries between farmers and institutions and can be used as efficient channels for project services, credit, and information dissemination. A farmers' organization accumulates experiences and learning, thus contributing to the growth, maturity, and ultimate sustainability of the farmers' group.

(3) Farmer organizations—not merely receiving project benefits but actively participating with farmers "owning" their research agenda—should be part of the institutional strategy of an ICRDP. Collaboration between farmer organizations and supporting institutions in an ICRDP should be encouraged without creating relationships of dependence among them.

The Brazilian ICRDP

In 1989, the Kellogg Foundation approved a 3-year grant (1989-1992) to CIAT and collaborating Brazilian agricultural research and technical assistance institutions and farmer organizations. The grant's overall objective was to support the introduction of improved cassava production, processing technologies, and appropriate organizational schemes for institutions and farmer groups throughout the main cassava-growing areas of Ceará State, Northeast Brazil.

In this region, an estimated 110,000 ha of cassava are harvested yearly with a total output of almost 1.2 million tons of cassava roots. For centuries, the main commercial outlet for production has been the *casas de farinha*. These are small communal processing units used to process cassava roots into a toasted flour or meal known as *farinha de mandioca*. This flour is a staple product and source of income, especially in the rural sectors of Northeast Brazil. In Ceará State, an estimated 14,000 *casas de farinha* produce almost 200,000 t of cassava flour per year, representing about 65% of the state's cassava production.

Northeast Brazil's extremely variable rainfall patterns cause wide fluctuations in cassava yields and so the supply and prices of *farinha de mandioca* vary greatly. Because the main income of the region's small-scale farmers derives from cassava flour, this situation creates instability. Further, poor quality, the small scale of operation, and rudimentary cassava processing technology further contribute to establishing commercial systems whereby farmer groups are forced to sell their product at low prices.

The ICRDP's strategy was to seek a large, alternative, market that cassava could enter, especially in good rainfall years when excess cassava production usually means low prices. Once the animal feed market was focused, a pilot project was established to develop the local experience needed to strengthen local institutional capacity for implementing cassava-based rural development programs with potential to benefit targeted groups. A long-term objective was to develop national capacity to carry out similar development programs in other regions of Brazil.

Two factors significantly benefited the project: first, counterpart agencies in the State had previously worked on relating small-scale cassava farming and processing. And, second, the State's institutional setup included top-level administrators, policy makers, and local agencies' staff who had been exposed to similar experiences in other countries. Their participation was fundamental in defining the project's organizational and operational strategies.

A state cassava committee (CCC), created before the project, was strengthened and soon gained general recognition as the coordinating body for project activities and all those related to promoting and developing the cassava crop in Ceará State. Regional cassava committees (RCCs) were established to decentralize project activity coordination and integrate the research and extension collaborating agencies in the project's area of influence.

The project's expansion, in terms of number of farmer groups organized, was explosive, mainly because national and state government agencies strongly intervened to launch programs of financial aid in the form of grants, thus allowing rural communities to build cassava drying agroindustries. From the 11 that had already existed at the project's start, the number of farmer groups rose to 158—about 75% were established during the project's last year (1991) (Figure 4).

The CCCs and RCCs played a crucial role in the task of approaching different government agencies and programs to obtain grants on behalf of the farmer organizations. At the same time, both these committees had permanent access to project funds for assisting and supporting farmer activities. Despite the adverse economic situation the country faced during the project's span, the committees were very active in identifying sources of financial support and channeling them toward targeted groups. Project activities

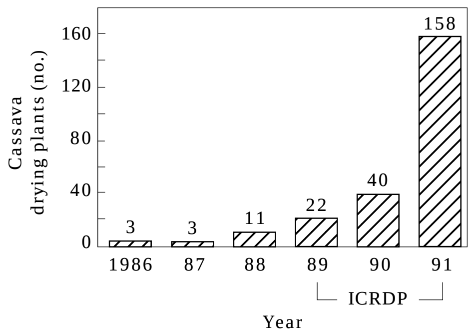

Figure 4. Expansion of cassava-drying agroindustries in Ceará, Brazil, 1986-1991. (ICRDP = integrated cassava research and development project.)

could therefore be executed within the proposed goals. Total financial support from local agencies during the project's 3 years was almost 1 million American dollars (not including local staff salaries).

The project in Ceará followed an implementation model similar to that of other ICRDPs, based mainly on transferring and adapting available cassava processing technologies. This took advantage of a strong extension service that allowed rapid cover of the region's main cassava-growing areas.

Project activities also included some production technology research. Initial results indicated that the adoption of improved technology components would help increase the region's cassava productivity by as much as 50%. However, these results are suggestive only because farmers did not have to pay the expenses. To what extent small-scale, poor-resource farmers would be willing to invest in, for example, organic fertilizers or weed control, remains to be assessed.

The relationship between *farinha de mandioca* and dried cassava chips as the two main commercial options for cassava farmers in Ceará determines the financial success of the cassava drying agroindustries the project promoted. When market prices for *farinha de mandioca* are low, the cassava drying plants function efficiently as an alternative market. Conversely, when prices for *farinha de mandioca* are attractive, then finding adequate supplies of raw material for the cassava drying agroindustries becomes difficult.

Skewed land and farm-size distribution, plus climatic fluctuations, also strongly influence the seasonal availability of cassava roots and thus the performance of the cassava processing units.

With only 3 years of implementation, a complete *ex post* evaluation of the project's impact is difficult. The speed with which cassava drying technologies are adapted for new regions and rural communities can be assessed through the pilot project's monitoring and evaluation system model (involving base data on 133 cassava-processing farmer groups), a survey conducted at the beginning of the project, and another at its end. The assessment can be done in terms of increased number of drying agroindustries and regions of influence, continuous increase in client numbers for dried cassava, and the degree of strengthening of the organizational structure implemented for both institutions and farmer groups, which, by the project's end, included state and regional cassava committees and farmer organizations.

A preliminary analysis of data from the two surveys indicates that on-farm consumption and use of cassava is changing. Farmers now sell a share of their production to the cassava drying agroindustries, in contrast with the situation before the project, when the *casas de farinha* were the main commercial outlet. Farmers participating in the project are starting to adopt the new processing technology. The new market has stimulated them to transform their patterns of cassava use and become more market oriented.

Qualitative information available on direct impact on community welfare, institutional support, and the general environment indicates that the pilot project served as a vehicle to increase community development in general (organization, knowledge, employment opportunities, incomes), and to strengthen local institutional support (technical assistance, working capital). However, the project's impact on cassava production and productivity was rendered negligible because of the lack of opportunities for farmers to purchase or rent additional land. Adoption of improved production technology was slow among the project's beneficiaries.

The Ceará ICRDP proved that small, cassava-based, farmer organizations were attractive to cassava producers. These groups first had to improve their marketing schemes. Early success indicates potential for consolidation through stronger institutional commitment to support efforts by farmer organizations. Those cassava-based agroindustries able to operate during the project helped create additional employment opportunities, opened alternative markets, stimulated local industry, raised farmer incomes, and encouraged overall community development.

Funds are now being sought for a second phase: to consolidate the results obtained during the pilot project and to demonstrate these technologies and results to other regions and farmer groups.

Benefits and Beneficiaries of the ICRDPs

Benefits generated by the ICRDPs are captured principally by farmer members of the cassava-based agroindustries (Gottret and Henry, 1994). Members can receive benefits from (1) a new market available for their cassava roots at more stable prices; (2) more employment (and training) opportunities in the cassava processing agroindustries; (3) value-adding second-rate cassava roots which previously had no market value and were basically written off before the introduction of cassava processing; and (4) the annual share of profits generated by the cassava-based farmer organizations. This last benefit is available only to organization members, whereas the other three apply to any member of the larger community within which the agroindustry operates.

The total income of farmer members of the Ceará cassava processing groups during 1989-1992 reached US$163,887.00, of which 37.3% corresponded to cassava root sales, 10.0% to processing wages, and 52.7% to sharing annual profits (Figure 5). Another source of benefits the project generated was captured by nonmembers responsible for selling 61.6% of the 7,080 t of cassava roots processed during the project. In contrast, in the Ecuadorean project, farmer members of the cassava-based agroindustries earned, over 6 years, an average annual income of US$225, whereas nonmembers earned US$89 (Figure 6).

Regarding direct economic benefits, for the Colombian ICRDP, almost 75% (US$16.2 million) of the total project benefits was estimated to accrue to cassava farmers (producers and processors) (Gottret and Henry, 1994). But considerable indirect benefits have also been generated: backward linkages to several small industries supplying materials for constructing and operating the drying plants; forward linkages include especially the income-generating effect from increased rural incomes. This will have a multiplier effect in that increased rural demand for goods and services will boost urban manufacturing. As such, rural agroindustries have a strong, positive effect on overall economic development.

The ICRDPs also represent an important source of benefits for groups such as women and landless farmers, who usually do not benefit significantly from projects. For

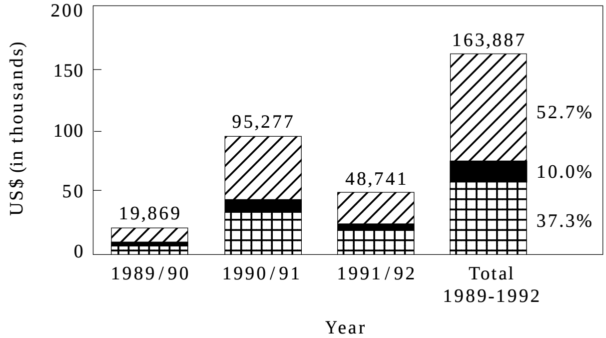

Figure 5. Total incomes for cassava-processing group members, Ceará, 1989-1992. Sources of income were = cassava sales; = processing wages; = annual profits.

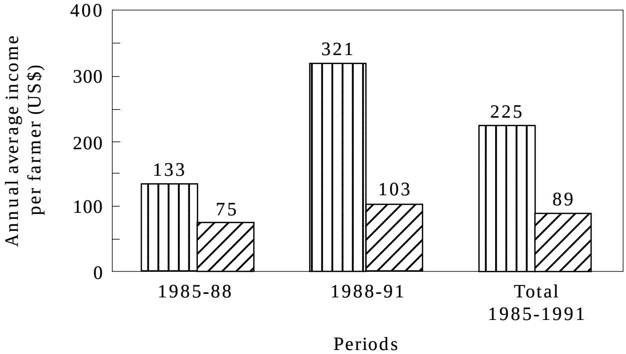

Figure 6. Income earned by members ( ) and nonmembers ( ) of cassava-based agroindustries, Ecuador, 1985-1991.

example, in the Ecuadorean project, US$15,000 was paid in 1990/91 for peeling cassava roots, 80% of which went to poor, nonmember, women and children who peeled cassava as their sole off-farm income. In the 1991/92 processing season, this amount even increased to 90%. In Ceará, Brazil, the distribution of income earned by farmers during the 3-year pilot project was 58.9% for smallholders, 32.4% for renters, and 8.7% for sharecroppers.

Other important benefits passed to the community in which the cassava-based agroindustries operated. Among these were easier access to credit programs and training opportunities, integration of institutional presence, and strengthening of community spirit. Increases in local income during the dry season resulted in increased purchases of foodstuffs and other items from local shops in rural communities, stimulating local economic growth. In some Manabí communities, the cassava-processing activity lessened migration of men to other coastal regions to work in the banana industry. The cassava-processing infrastructure can be used for other commercial and cultural activities. For example, in Ecuador, cassava-drying patios are rented to dry other products (maize, castor beans, cocoa, rice). Associations hold community *fiestas*, charging entry to earn money. The drying patios make excellent dance floors!

In several communities, the cassava-based associations have motivated the creation of day-care centers, and encouraged the building of roads and bridges, sponsored with government funds. In Ceará, the wives of ICRDP members started small, poultry fattening operations beside the cassava-drying floors to generate complementary income.

Types of Institutions and Their Functions in ICRDPs

The ICRDPs, in which different activities have to be developed simultaneously (e.g., production, processing, marketing, organization, training, and monitoring), are integrated by nature. Because they are based on farmer organizations, they generate demand for substantial resources and coordinating mechanisms from other institutions. The organizational structure of any ICRDP must be sufficiently flexible and adaptable to incorporate different farmer organization schemes and institutional configurations. Table 3 shows the range of institutions currently participating in projects in Colombia, Ecuador, and Brazil and the different functions each performs.

In Brazil, state institutions played leading roles, while second-order farmer organizations were slow to form. In contrast, in Colombia, the second-order farmer organizations led the commercialization activities and some large-scale input buying. But few other activities, such as research, were coordinated. In Ecuador, a wide range of institutions played a multitude of roles, but the UATAPPY was the key player for virtually all ICRDP functions.

Recommendations for Successfully Implementing ICRDPs (Lessons Learned)

The ICRDPs now under way in several Latin American countries have provided a dynamic framework within which CIAT's Cassava Program has been interacting with various national institutions, whether research- or development-oriented, and with farmer groups. This interaction has made it easier to validate and adapt existing production and postharvest technology, together with the techniques developed for market analysis. Hopefully, these generalized methodologies for implementing ICRDPs will be adaptable to different economic conditions, farming systems, institutional capacities, and markets. Based on the experiences that the Cassava Program has built up over the past years, some critical factors have been identified, which need to be addressed if ICRDPs are to be successfully implemented.

Product and market development

Until now, for marketing cassava roots, ICRDPs have depended on the traditional market (human consumption) and a new market (animal feed). Recently, they have begun to diversify considerably, both consolidating the markets for existing cassava products and creating new products for new markets. This, in turn, has forced attention on improving market financial management and quality control. The long-term viability of the model depends on the farmer organizations' ability to move their products into a wider range of markets or to develop a broader range of end uses for the product, especially those that can offer a high margin of profitability (added value). This not only applies to cassava but also to other commodities produced by farmer organizations.

Table 3. Types of organizations and their functions in integrated cassava research and development projects (ICRDPs).

Function of organization	Region in country[a]		
	North Coast (Colombia)	Manabí (Ecuador)	Ceará (Brazil)
Agricultural research	ICA	INIAP	EMBRAPA EPACE
Technical assistance	ICA		EMATERCE
Rural development	DRI	FODERUMA	SUDENE
Credit	Caja Agraria		Banco Nordeste
Farmer organizations:			
First order	180 groups	18 groups	165 groups
Second order	ASOCOSTA ANPPY	UATAPPY	COOPEMUBA COPROMA
Nongovernmental	FUNDIAGRO		Esplar
International	CIAT ACDI	USAID	CIAT IBRD Kellogg Foundation
Governmental:			
National	Min. of Agriculture	Min. of Agriculture	Ministry of Agriculture
Regional	Sec. of Agriculture	Sec. of Agriculture	Sec. of Agriculture Sec. of Industry and Commerce

a. Colombia: ICA = Instituto Colombiano Agropecuario; DRI = Fondo de Desarrollo Rural Integrado; ASOCOSTA = Asociación de Cooperativas de la Costa; ANPPY = Asociación Nacional de Productores y Procesadores de Yuca; FUNDIAGRO = Fundación para la Investigación y el Desarrollo de Tecnologías Apropiadas al Agro; ACDI = Agricultural Cooperative Development International.

Ecuador: INIAP = Instituto Nacional de Investigaciones Agropecuarias; FODERUMA = Fondo para el Desarrollo Rural del Ministerio de Agricultura; UATAPPY = Unión de Asociaciones de Trabajadores Agrícolas, Productores y Procesadores de Yuca; USAID = United States Agency for International Development.

Brazil: EMBRAPA = Empresa Brasileira de Pesquisa Agropecuária; EPACE = Empresa de Pesquisa Agropecuária do Ceará; EMATERCE = Empresa de Pesquisa, Assistência Técnica e Extensão Rural do Ceará; SUDENE = Superintendência do Desenvolvimento do Nordeste; COOPEMUBA = Cooperativa de Productores de Mandioca de Ubajara; COPROMA = Cooperativa de Productores de Mandioca de Açarau; IBRD = International Bank for Reconstruction and Development (the World Bank).

Crop production technology research

Developing and adopting cassava production systems that will sustain or increase productivity and reduce costs are critical to the ICRDPs' success. For cassava to continue competing, more intensive farm practices may have to be introduced, thus risking increased pressure on the natural resource base. Research and development on suitable production systems must be initiated, continued, and strengthened. This requires introducing adapted genetic materials, carefully exploring additional alternatives to maintain and enhance soil fertility, and adapting ecologically sound, crop protection practices.

Sufficient evidence exists to prove that small, cassava-based, farmer organizations can function as efficient and effective enterprises and, as a result, as vehicles for adapting and transferring production technology. The challenge is to make them efficient and dynamic private sector enterprises.

Interinstitutional coordination

Institutions. Interinstitutional coordination is important to bring together the expertise needed to support the farmer organizations in the different areas and activities handled by the ICRDPs. At their inception, these projects involve diverse activities, beyond the scope of any single institution. The interinstitutional coordination mechanisms that an ICRDP requires are usually new to local organizations, who will need an adjustment period to function appropriately and efficiently. To ensure smooth coordination, one institution should be designated as "coordinator" among the rest, and sufficient funds should be allocated.

In summary, successful interinstitutional coordination must include at least (1) the identification of a coordinating institution, (2) agreement on the necessary functions of each participating institution, and (3) development of coordinating mechanisms at project, regional, and national levels.

Farmer group, or organization, or enterprise? Small, cassava-based, organizations has proved attractive to cassava producers who rapidly build their organizations. But first-order farmer organizations are usually exceptionally weak in business management and administration. Suitable instruments and methodologies for improving these skills are not always available, and if they are, their use is often hindered by very low levels of education.

If the ICRDPs are to achieve autonomy in the medium term, then they must help form second-order farmer organizations that can (1) support their members with a wide range of services, from marketing, through technical assistance, to applied research, and (2) represent their members in dialogue with other collaborating institutes or with government policy makers (creation of lobbying power). In Ecuador and, to a lesser extent, in Colombia, farmer second-order organizations are playing these roles and giving authority and autonomy.

The interests of farmer, cooperative-based, agroindustries must be reconciled with those of small or medium-sized entrepreneurial agroindustries. In the Colombian project, conflicts have already arisen.

The organizations, including cooperatives and associations, need to be efficient, dynamic, and market oriented to be commercially successful. The social objectives of these groups are seen principally by the way profits are distributed. Long-term sustainability depends heavily on commercial survival.

Human resource development

Poor human resource development is a well-known constraint to the implementation of any rural program. Training and networking are two important strategies to counteract it.

Training. Establishing ICRDPs in several Latin American countries has highlighted the region's deficiency in institutions and personnel specialized in postharvest research and development, including marketing. Thus, a great demand exists for training research and extension personnel and farmers in such areas as cassava processing, crop management, basic accounting, production technology, human and financial resource management, marketing, market analysis, monitoring, and evaluation.

Experiences accumulated in various countries where ICRDPs have been implemented, especially Brazil and Colombia, show that training activities have been mainly oriented toward building capacity among local agency staff rather than among farmers, given the class structure and organizational profile of their institutional environment. Ecuador has been an exception to the tendency: the UATAPPY and collaborating institutions carried out farmer training. Training strategies for technicians should link training and work, using current and real work-related problems as the training issues, and work groups as the basic training unit. The sharing of training, management, delivery, and participation has resulted in greater collaboration among partner institutions.

Educational and organizational needs of cassava producers are much greater than those of project staff. High rates of illiteracy and lack of organizational skills (particularly those related to handling funds, keeping records, organizing meetings) are among the major constraints to increased farmer participation in ICRDPs and to a more efficient, two-way information flow between them and project staff.

The current farmer-training strategies that local agencies and technicians use in most ICRDPs tend to include mainly formal training and mass communication activities centered on extending technological services rather than on training and education. As such, these training methodologies tend to be useful only for those farmers with the needed skills. This results in segregating the rest of the community, making it more difficult to develop a broader leadership base at the community level. The Ecuadorean ICRDP, however, tried to improve this by having an explicit UATAPPY training function. It designated a UATAPPY member (farmer) to manage this function and trained this person to carry it out in a highly professional manner.

Networking. Forging links within and among regions and countries is one important aspect of implementing ICRDPs. At a regional or national level, it is sometimes hard to achieve the interinstitutional and interdisciplinary approach needed to translate new or improved production and postharvest technologies into commercially viable activities. The project framework, within which ICRDPs are usually implemented, facilitates integrating several national institutions into a network that provides a forum for interchanging experiences and methodologies and for resolving problems common across regions and projects.

The Cassava Program at CIAT and its partners in many national institutions have developed methodologies over the last 12 years that have been operationally, economically, and technically viable. Regional and national networking seems to be the best way of ensuring that accumulated experiences and knowledge can be made available to other regions and countries facing similar problems and opportunities.

Monitoring and evaluation

Project monitoring and evaluation (M&E) has been an integral part of the ICRDPs' methodology from the start. Besides its use in defining potential markets, research priorities and sites, and beneficiaries, it has proved essential for short-term decision making in refining specific objectives, then undertaking appropriate actions.

During the early 1980s, an M&E system was designed to be carried out at three levels, using different methodologies: (1) continuous update of a database on farmer organizations; (2) an annual survey of a large sample of collaborating farmers; and (3) intensively monitoring a subsample of farmers (Bode, 1991).

For the first ICRDP in Colombia, the M&E system worked well in the beginning, but as the project matured, the database updating and subsequent annual reports based on its data became the only activities and outputs of the M&E system, with much of the data underused. Furthermore, the annual report was circulated to only a few collaborating institutions, with insufficient feedback to the farmer organizations themselves. The monitoring model was seen as suitable only for the pilot phase of a cassava-based development project, being too static to evolve with the project—different levels of project maturity required different emphases and aspects for M&E.

An improved model of M&E was developed for the Ecuadorean and Brazilian projects. First, key to several of the M&E limitations, was the model's organizational structure and execution, which had to be based "in house." That is, the second-order farmer organization had to internally analyze the M&E system and coordinate its operation. Collaborating institutions should adopt only technical assistance roles. An effective feedback of appropriate information is thus delivered in timely fashion to relevant audiences.

Second, the M&E system should allow for the dynamics of the project itself. Parameters of interest during the project's early stages may not be relevant for its expansion phases. Adoption and impact studies need to be included, but only at later stages. Different M&E activities thus become important as the project matures (Henry and Best, 1994). Table 4 shows how different monitoring activities are introduced according to the project's

Table 4. A modified monitoring and evaluation model for an integrated cassava research and development project.

Activity	Source[a]	Pilot stage: Experimental	Pilot stage: Semicommercial	Commercial stage
Short-term monitoring:				
Technical	1, 2	X	X	X
Financial	1, 2	X	X	X
Social	2	X	X	
Commercial	2	X	X	X
Institutional	2	X	X	
Long-term monitoring:				
Markets	2, C	X		X
Models	2, C			X
Adoption:				
Processing plants	2		X	X
Production technology	2, C		X	X
Other technologies	2, C		X	X
Impact:				
On-farm / processing plant	2, C	X		X
Community	C			X
Aggregate	C			X

a. 1 = first-order farmer organizations; 2 = second-order; C = collaborators such as institutions, universities, and nongovernmental organizations.

SOURCE: Henry and Best, 1994.

evolution. For example, market studies need to be conducted at the experimental phase to suggest viable, potential markets for the project. But markets are dynamic so the market studies need to be repeated later to ensure a sustainable market potential or, as in the case of the Ecuadorean experience, to look for product and market diversification opportunities (Brouwer, 1992; CENDES, 1993).

Another feature of the new M&E model is that the intensiveness of data collection diminishes as the speed of adoption increases.

The new M&E model has already proved to be superior in that it is both more usefully effective and has increased efficiency in using resources while contributing to the project's sustainability. In Colombia, for example, results of adoption and impact studies have been fed back to research managers, scientists, second-order farmer organizations, policy makers, and donors for different specific uses. In Ecuador, more market studies have been recently conducted, which generated evidence of potential demand for alternative cassava flour uses in nonconventional, industrial products (CENDES, 1993). In Brazil, cooperative-level processed data have been fed back to farmer organizations within a month, allowing them to assess their own performance and relate it with that of other farmer groups.

Policy support and decisions

From their very inception, ICRDPs have been closely related to and affected by policy decisions and support. For example, all countries in tropical Latin America are net importers of cereals and most governments in the region have tried to supply this increasing demand for carbohydrates through policy interventions and subsidized production credit. This has meant that traditional starchy staples, such as cassava, have had to compete with grains at a substantial disadvantage.

Exploiting postharvest opportunities for root and tuber crops is currently less of a technological problem, given the extensive expertise available. The central issue in developing cassava-based markets and products is the economics of the whole production and marketing system. This is directly affected by policy interventions oriented toward strengthening the bargaining power and the organizational levels of cassava producers.

In the Colombian project, policy issues were present from the very start. The pilot project was begun in an area where an on-going land reform program was operating: farmers were receiving credit and technical assistance aimed at increasing cassava production in the region. Farmer organizations even had access to credit for cassava production and processing and for constructing processing infrastructure. The Government controlled cereal imports and included dried cassava in the policy of minimum prices for agricultural products. This latter policy was first established, on a six-monthly basis, in 1990 by the Ministry of Agriculture.

Policy issues became even more important during 1993/94 when decreased import duties (a result of Colombia's economic aperture) allowed high-quality cassava pellets from Indonesia to be imported at "dumping" prices. This act set off a series of high-level discussions that brought together representatives of government research and extension institutes, the private sector, second-order cassava-processing organizations, and CIAT. They then discussed the framework, individual responsibilities, and an action plan for a collaborative, long-term effort to optimize the economic sustainability of the cassava sector in the North Coast in general and of the ICRDP in particular.

In the Ecuadorean project, the lack of government intervention to provide small-scale credit has been crucial in impeding the establishment of cassava-based agroindustries, preventing project activities expanding to other potential regions and cassava-producing areas.

In the Brazilian project, cassava farmers benefited from policy decisions. Ten financial programs provided grants that helped establish cassava-processing plants. Two credit programs for cassava production and processing, based on price variation of cassava products, provided a certain stability of credit for farmers within the country's highly unstable economic situation, typified by inflation rates of 25%-30% per month.

Conclusions

Three key conclusions result from the comparative analysis of the three ICRDPs (North Coast region, Colombia; Manabí Province, Ecuador; and Ceará State, Brazil).

(1) Integrating production, processing, and marketing research and development activities

The ICRDPs clearly demonstrate that research and development must be integrated if the cassava crop's full potential is to be effectively realized. The intertwined relationships and dependencies of production, processing, and marketing make it inefficient and illogical for institutions—whether national or international—to work exclusively on any one cassava activity in isolation from the others.

The ICRDPs provide an appropriate mechanism to bring together these activities in a context where several kinds of institutions—including farmer organizations—can collaborate effectively.

For CIAT, as an international research center, the ICRDPs have provided a crucial testing-ground for linking production and processing technologies, and for developing appropriate socioeconomic tools for market and monitoring research. The feedback from the results has served to shape priorities for future CIAT research directions. To maintain relevance to cassava farmer and processor needs, CIAT must preserve strong links with ICRDPs activities and an equally strong human and technical resource capacity in the areas of production, postharvest, and socioeconomics. Partnerships and collaborative arrangements between CIAT and national entities are a must for future activities.

Strengthening farmer organizations and their links to research and development are critical objectives for the future. The ICRDPs offer both international and national institutions a framework on which to build collaborative working arrangements with farmers through their organizations.

(2) Providing important social and economic benefits

The ICRPDs fulfill this role to holders of small and medium-sized farms and landless rural workers in marginal farming sectors with few alternatives. Cassava's exceptional adaptability to such marginal areas makes it a natural indicator for poorer households and an appropriate vehicle for organizing farm-level, income-generating, productive activities. The ICRDPs act as "magnets" for other types of development efforts and can provide a base to anchor and integrate these, thus contributing to increased social stability and economic growth.

(3) Farmer investment in improved production technologies

The ICRDPs have clearly proved that when increased value for the cassava crop is created through identifying new markets and developing new products to suit these markets, farmers will invest in improved production technologies. Providing an appropriate incentive for farmers to invest in their cassava production systems has profound implications for using new technologies to increase productivity and to induce resource sustainability.

Future Steps

Looking beyond the immediate conclusions drawn from the ICRDPs' current experiences, one can see several important tasks yet to be accomplished.

First, despite the many years of collaboration between national programs in ICRDPs, there is relatively little consolidation of the experiences and lessons learned from the individual projects, and what has been written is not yet widely available for public use. Most of the experiences remain lodged in the minds of practitioners who dedicated considerable portions of their professional careers to these projects. CIAT must make a concerted effort to document these experiences, analyze the results, and make them available for wider consumption.

Second, there is a crucial need to couple this documentation with training programs that distill the ICRDP methodologies from case experiences, and transform them into appropriate training materials. These, in turn, will provide the vehicles by which others will learn how to plan and implement ICRDPs in other cassava-producing regions in Latin America, Africa, and Asia. Concomitantly, such materials need to be dynamic, that is, created in a format that allows new lessons and experiences from more recent projects (on all three continents) to be assessed and incorporated.

Third, the ICRDPs would gain time and reduce duplication of negative experiences through networking and exchanging visits between projects and through training and technical assistance between technicians and farmers. But no structure exists to continue such exchange and collaboration. Funding and leadership are needed to create this structure. CIAT could contribute significantly by establishing norms for such interactions to take place.

Technology generated by public funds and agencies must remain freely accessible in the public domain. At the same time, private sector participation must be encouraged and its interests understood and accommodated in an equitable fashion. This will require considerable international diplomacy and negotiation.

If a networking program is first placed within an existing, agroindustrial, regional network (e.g., Programa para el Desarrollo Agroindustrial Rural [PRODAR] in Latin America and the Caribbean), then administrative costs would be reduced and duplication of efforts prevented. The ICRDP experience would be passed to other productive sectors or commodities that could benefit from this integrated approach. Likewise, the ICRDPs would benefit from connections to other possible agroindustrial technologies that could diversify current farmer organizations' outputs.

Linking an ICRDP from Latin America and the Caribbean region with those of similar interests in Africa and Asia may create further possibilities for internal growth, lessen duplication, and reduce technology development lag time. It could create greater horizontal exchange across regions where similar cassava problems and opportunities exist. These efforts may encourage farmer-to-farmer communication and assistance across large distances and perhaps enable cassava development to occur in areas where other, more costly, institutional efforts have failed.

Finally, because cassava is often grown in marginal environments where the resource base is rapidly being degraded, ICRDPs offer an ideal opportunity to explore with farmers the questions and problems of long-term sustainability for cassava-integrated systems. Farmer-processors who have *learned and earned* the value that new markets can give their cassava crops have an incentive to conserve their resource base and ensure that its productivity will endure. Such farmers and their organizations can become willing collaborators in expanding the ICRDP's focus to a landscape perspective where the longer term management of cassava is but one part of a complex resource management system.

Mature ICRDPs must now turn toward these more complex problems and begin to focus attention on longer term sustainability. Explicit attention must be directed to the systemic impact of cassava production and processing, including work on productive capability, water and waste management, and relationships with complementary and competing systems. If ICRDPs can indeed widen their horizons and incorporate these issues and problems, then they may achieve a long-term, positive impact on the lives of rural people depending on cassava.

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CHAPTER 39

THE CASSAVA FLOUR PROJECT IN COLOMBIA: FROM OPPORTUNITY IDENTIFICATION TO MARKET DEVELOPMENT

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Abstract

The cassava flour project in Colombia began in 1984 with financing from the International Development Research Centre (IDRC). It seeks to increase the income of small farmers in cassava-growing areas by creating an agroindustry focused on the production of cassava flour for human and industrial consumption.

The following discussion of the project "Production and marketing of cassava flour in Colombia" outlines the underlying methodological framework, and describes the project activities executed during the research, pilot project, and expansion phase. Emphasis is given to the pilot project.

Methodological Framework

The project uses integrated project and product development methodologies. During the research stage, activities can be seen as belonging to one or the other methodology (Figure 1), but as blending in the pilot project.

Product development concentrates on three main areas: first, the generation, evaluation, and selection of ideas for new products, in this case cassava based; second, the development of a product prototype and process design, accompanied by industrial and/or consumer research; and, third, product presentation, that is, quality specifications, product name, and packaging.

The term "integrated cassava project" describes a rural development strategy, executed in three phases by rural inhabitants, to promote the agroindustrial transformation of cassava through the integration of production, processing, and marketing functions and supported by governmental and nongovernmental organizations.

The research phase is in two parts: national analysis, in which the national economy, the commercial outlook for cassava, and the potential of ideas for new cassava-based products are studied to select new products and a region. In the second part—regional analysis—the selected region is studied in greater detail, especially regarding cassava production, farmer organizations, and nearby markets, to select the best scenario for a pilot project.

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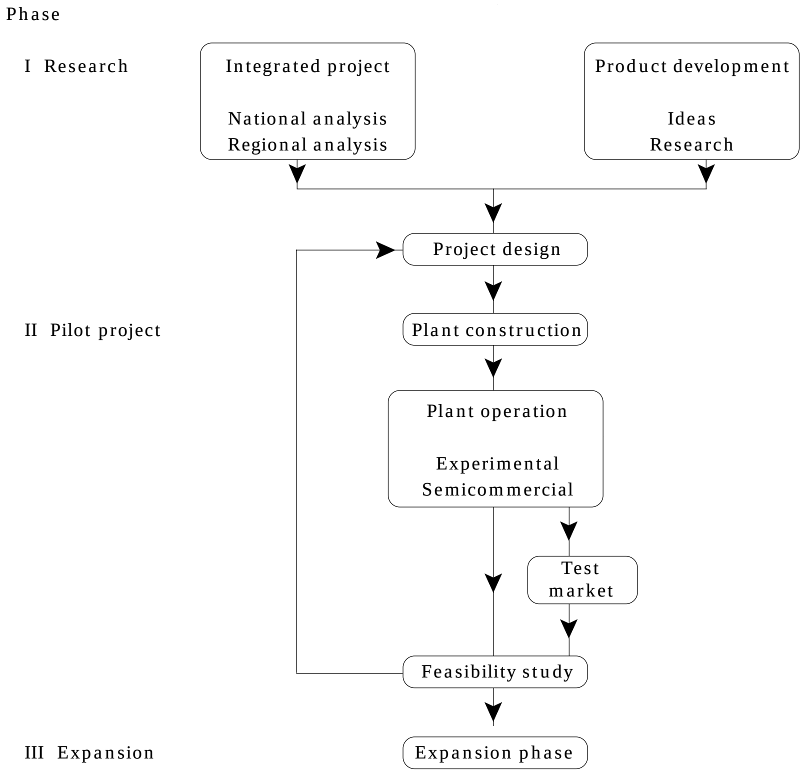

Figure 1. Outline of the integrated project and product development methodologies.

During the second phase—pilot project—a pilot plant is established and operated semicommercially under real market conditions to determine the feasibility of the agroindustry.

In the final phase—expansion—the processing units are replicated and the market for the product is expanded to consolidate the new agroindustry.

Evolution of the Cassava Flour Project

Research phase

The objective of this first phase was to determine the technical and economic conditions required for developing the cassava flour agroindustry in Colombia. The main use anticipated for cassava flour was in the preparation of a wheat and cassava composite flour for bread making.

The region selected, the North Coast—also known as the Atlantic Coast—is the main cassava-producing area in Colombia, with the root grown mostly by small-scale farmers. Accordingly, the economy of cassava production in the North Coast was studied, along with the wheat-milling and bread-making sectors. The equipment for small-scale rural processing of cassava was adapted and developed. In addition, the influence of cassava varieties on the quality of cassava roots and derived products was examined. Surveys among consumers and bread makers were conducted to evaluate the acceptability of breads made from composite flours of wheat and cassava.

The research concluded that the development of a cassava flour agroindustry was viable because cassava flour could be sold at lower prices than wheat flour, and consumers found the composite bread acceptable. However, bakers saw a high risk in lowering the quality of their products by using cassava flour.

The decision was made to continue with the pilot project, on the understanding that alternative markets for cassava flour were identified.

Pilot project phase

In this phase a pilot cassava flour plant was set up and operated under real market conditions to assess the feasibility of establishing the new agroindustry. The following activities were carried out:

Adjusting and evaluating production. A set of criteria (such as stability of farmer organizations or performance of cassava crops) was determined and used to select the site for the pilot plant at Chinú, Córdoba. The Cooperativa de Productores de los Algarrobos (COOPROALGA) was chosen as the executing farmer organization. The pilot plant was designed, and a local civil engineering firm built it within 3 months. Most of the equipment and machinery was manufactured in a Cali workshop but the metallic coal burner was available commercially. A well was dug to supply the plant with water.

Workers and administrative personnel were selected and trained. A daily and weekly timetable of activities was drawn up and an almost year-round supply of fresh cassava roots coordinated. In total, 42 t of dried chips were produced and transported by road to be milled in a commercial wheat mill in Medellín.

An information system for production was developed and implemented, and control parameters established. Specifications for the quality of raw material and sanitary controls were drawn up. The microbiological quality of the cassava flour was monitored, and variable costs of production closely supervised.

Support research was conducted, with the collaboration of the Universidad del Valle (UNIVALLE) and the Natural Resources Institute (NRI), UK. Areas investigated included the improvement of processing equipment, control of microbiological quality of cassava flour, development of a small-scale milling system for cassava chips, research on storage of cassava products, and development of moisture-measuring equipment for cassava products.

Testing and demonstrating an improved cassava production technology for the North Coast. Since 1989, 120 farmer-managed pre-production plots for demonstration were established on the North Coast with cassava-maize and cassava-maize-yam combinations; farmers were supervised by an agronomist.

The recommended technologies, which improved maize and cassava yields, combined adjustments in the use of preemergent herbicides, fertilization of maize and yam, more intensive use of human labor, and use of improved maize varieties.

Identifying markets for cassava flour and product promotion. As described above, the focus on bread making was modified after the research phase. Market opportunities were sought in other food industry categories where cassava flour would have an equal or better functional advantage or where it could be substituted, partially or completely, for other flours or starches.

A market study was conducted nationally among food companies of different sizes. The study first focused on products marketed and raw materials; then, flour samples were distributed for substitution trials; and, finally, feedback was obtained on the trials and buying intention was gauged. The study showed that potential markets for cassava flour included processed meats, cookies, ice-cream cones, pasta, pastry, soup and sauce mixes. Cassava flour exhibits functional advantages in most of these products. More than 80% of the volume would be destined to replace wheat flour. Assuming that cassava flour could be sold for 10% less than wheat flour and that there would be adequate promotion, the estimated mid-term market demand would be 20,000 t/year.

The promotional effort concentrated on Medellín, which had milling facilities and the largest single market detected in the study. Sixteen firms were visited and given free samples of flour. The subsequent trials were closely monitored. Inferences from this experience were that the microbiological quality was not acceptable to most companies, that the food industry was conservative, and that sales efforts would benefit from better technical information on cassava flour.

The flour developed was yellowish white and contained about 80% starch. Its granule size was smaller than that of wheat flour. It was called "Yukaribe," and packaged in polypropylene sacks, complete with a graphic design. The flour was priced at 15% below wheat flour.

Feasibility of the agroindustry: pilot project phase. A computerized financial model of the pilot plant was designed and updated periodically to monitor production costs, plant efficiency, and profitability. At the end of the pilot project phase, the feasibility of the cassava flour agroindustry was seen as follows:

(1) *Technical feasibility*. The artificial drying process was inefficient; and the microbiological quality of cassava flour was substandard.
(2) *Commercial feasibility*. Additional technical information was required. The physicochemical and microbiological qualities needed improvement.
(3) *Cooperative-management feasibility*. Sales and marketing personnel were needed to handle product marketing.
(4) *Economic feasibility*. The financial rate of return (FRR), a profitability parameter, was calculated at 22%, which was considered low.

Expansion phase

The project could not proceed with a formal expansion phase because of the constraints described above, but some action could be taken in preparation for a future expansion. A hybrid pilot/expansion phase was developed to convert the pilot plant into a commercial operation with improved profitability.

Artificial drying costs were greatly reduced by doubling heat generation and switching from coke to mineral coal. This resulted in a shorter drying period and improved flour microbiological quality.

The plant received a small cassava-chip mill, developed jointly by CIAT and UNIVALLE. The mill consisted of a premilling component that reduced chip size and two cylindrical screens that also functioned as mills. The output was a first-grade flour (70%-85% extraction) and bran. In-plant milling reduced variable costs and contributed toward satisfying local demand for the product.

Members of COOPROALGA, the farming cooperative managing the pilot plant, were trained in the administration of small enterprises.

Developing and executing a plan for expanding the cassava flour agroindustry in Colombia. Cassava flour was promoted among the North Coast food industries, especially meat-processing, cookies, and spices, with the eventual penetration of the meat-processing sector.

However, to increase sales further, the marketing strategy was changed and cassava flour was promoted in nonfood industries—especially adhesives and plywood—where microbiological quality was less important and higher market prices could be obtained. Adhesive companies in major Colombian cities were provided with samples of cassava flour and, simultaneously, the Fundación para la Investigación y el Desarrollo de Tecnologías Apropiadas al Agro (FUNDIAGRO) provided support in the development of cassava flour-based adhesives. The adhesive markets in Cali and Barranquilla were penetrated, although industrial requirements demanded increased flour purity by reducing the extraction rate during milling.

The design of the prototype building for the processing plant was revised to reduce costs and increase performance in accordance with the pilot project experience. Designing involved a team of architecture students from UNIVALLE, supervised by a member of the university staff.

Training materials, including videos and manuals on production and management, were developed.

Feasibility of the agroindustry: expansion phase. By the end of 1993, the feasibility status of the cassava flour agroindustry was seen as follows:

(1) *Technical feasibility*. Food industry: yeasts levels were too high. Adhesives industry: no limitations.
(2) *Commercial feasibility*. Food industry: additional technical information on cassava flour was required by firms; physicochemical and microbiological quality required improvement; cassava flour price is competitive against wheat flour only in the North Coast. Adhesives industry: additional technical information was required by firms.
(3) *Cooperative-management feasibility*. Food and adhesive industries: sales and marketing personnel were needed to handle product marketing.
(4) *Economic feasibility*. Food industry: FRR was 26%. Adhesives industry: FRR was above 30%.

Conclusions

The major outputs of the cassava flour project were:

(1) The development of an efficient small-scale system for cassava flour production.
(2) Although members of the executing cooperative had been trained to manage the plant, a major priority was to improve the quality of the raw material used in

the plant, including industrial varieties.

(3) Project feasibility is uncertain, because of high costs, deficient supplies, poor quality of the region's cassava roots, and insufficient entrepreneurial capacity of the executing cooperative.

(4) To plan successful rural agroindustrial projects, the following points must be considered:

   (a) the importance of the integrated, or entrepreneurial, approach, encompassing interventions in production to guarantee a sufficient supply of low-priced, quality raw material;
   (b) the need to assign enough funds and time for product development and marketing; and
   (c) the need to identify project executors with entrepreneurial abilities.

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CHAPTER 40

WOMEN AS PROCESSORS AND TRADERS OF CASSAVA FLOUR: THE PHILIPPINE EXPERIENCE

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Abstract

Earlier surveys revealed that cassava chipping is traditional among women in Mabagon, a cassava-growing village in the Philippines. This paper discusses the experiences gained from the pilot project conducted there to increase the women's processing efficiency by improving cassava chip and flour processing technologies and to assess opportunities for market expansion.

An association, consisting mostly of women (16 out of 19 members), was organized and trained to operate the pilot plant and to promote and market the cassava flour produced. The pilot operation began in October, 1991. The association now produces 20-75 bags (at 20 kg/bag) of cassava flour per month. These are sold to nearby bakeries, which use the cassava flour to prepare different baked goods. Plans for a full-scale commercial expansion are already under way.

Introduction

Root crops are given high priority because of their ubiquity in upland areas, which comprise about 15%-20% of land use in the Philippines. About 500,000 small-scale and marginal farmers rely on root crops for food security and supplementary cash income. Because the traditional ways of consuming root crops are few, optimizing their uses depends on an expanded agroindustrial market. This means focusing on postproduction technology.

Studies in Asia and Africa have shown that women farmers are largely involved in postharvest activities, particularly selling and processing. Thus, the "Women in Postproduction Systems" (WIPS) Project" was conceived to improve women's efficiency in postproduction activities and increase household incomes. This was first spearheaded by the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), collaborating with the Philippine Root Crop Research and Training Center (PRCRTC), the National Postharvest Institute for Research and Extension (NAPHIRE), and the Isabela State University (ISU) for root crops, rice, maize, and groundnuts. Funding came from the International Development Research Centre (IDRC).

Previous surveys in the Philippines showed that women are active as farm

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helpers, sellers, and processors of root crops into native delicacies. An important finding was the indigenous processing of cassava into dried chips in the islands of Leyte, Bohol, and the Camotes, and Misamis Oriental Province, for feed, food, and trade. Women were largely involved. This finding provided an opportunity for intervention by the project.

A diagnostic survey of root-crop farming households in Leyte Province, and an inventory of possible technologies that could fit into local systems, helped develop the idea of introducing components of cassava flour technology (which uses dried chips) to women farmers in the area around the town of Hindang, Leyte Province. The chips made in this area are of relatively good quality for flour.

This paper serves as a methodological note on the PRCRTC's experience in cassava flour processing and commercialization, involving mostly women. This phase, which started in October, 1991, is an integral component of the WIPS Project.

Objectives

The project has the following objectives:

(1) To introduce root-crop equipment that would improve the efficiency of cassava flour processing in a selected community (i.e., Mabagon village near the town of Hindang, Leyte Province).
(2) To test storage technology for dried chips and flour.
(3) To strengthen the capability of beneficiaries in organizational and entrepreneurial skills.
(4) To assess the effects of the introduced technologies on farming households.

Project Site and Beneficiaries

The project site is Mabagon, a village with a little more than 100 farming households, situated about 3 km to the northeast of Hindang. Copra (from coconut) and palay (from rice) are the main agricultural products of Hindang's hinterland, But most of the lands planted to these crops are owned by a few, relatively rich, landholders.

Small-scale farmers farm the uplands, 70% of them owning the land they till. A transect showed a predominance of upland cultivation of either sequential cropping or intercropping of cassava, sweetpotato, maize, vegetables (string beans, ampalaya, eggplant), and upland rice, with patches or fringes of taro and banana.

Most men receive income by working as hired hands (planting, harvesting, threshing) in the rice fields, selling upland cash crops (such as root crops, bananas, and vegetables), and raising livestock. Most women are engaged in selling various farm products and processing cassava, on the farm, into dried chips for feed.

This mixed farming system, where indigenous cassava processing plays an important role, was a promising match for village-based, cassava-flour processing and "shovel" feed mixing from byproducts. More especially, the local system fitted the project's particular concern for gender roles in farming systems and for improving women's cassava postproduction activities.

The Mabagon Root Crop Association (MARCA), the core group of collaborators, consisted of 19 farmers and processors: 3 men and 16 women. It was formed after several consultations among the local people and was finalized during the general assembly in December, 1991. Membership was voluntary; interest, commitment, and availability for the groups' activities were prerequisites. Currently, MARCA's registration as a cooperative is in process, with all requirements already met.

Technologies

The component technologies, pilot tested for cassava flour processing, included:

(1) PRCRTC-developed, village-level, cassava flour processing machines (chippers, modified *tapahan* dryer, grinder, and flour finisher).
(2) Storage for chips.
(3) Technology for byproduct use, that is, a neutral-scale "shovel" technology, in which cassava meal is mixed with other ingredients to produce a feed for swine.

In the initial phase of commercialization (toward the middle of the second year), expansion of market uses was explored. This led to new food-processing products technologies and, therefore, new bakery products being introduced to bakeries and to MARCA (e.g., *cacharon* [a puffed product with various flavors], *polvoron*, and processing cassava sticks and chips from fresh roots).

Methodology

The project took an integrated process approach, that is, a set of strategies was developed to coordinate needed components and was flexible enough to allow redesigning as new or improved methods were tested, refined, and disseminated through the targeted beneficiaries. This approach was essential for the project's success at the village level, where uncertainties were common and the reaction of people to introduced innovations unknown. The project was integrated in the sense that a multidisciplinary team implemented it, coordinating the phasing of various components, both technical and socioeconomic.

This approach is characteristically systems-oriented, interdisciplinary, participatory, and oriented by users' perspectives, local knowledge, practices, and norms.

Project implementation involved carrying out activities of different components designed in a stepwise but interphased manner to effectively transfer the technology to a functioning enterprise (Table 1).

MARCA: Its Progress to Date

Registration

By consensus, MARCA was first organized as an association and registered with the Department of Labor and Employment (DOLE). This was partly because about half of the members, at first, resisted a cooperative registration, seeing a conflict of interest with an already existing cooperative in the village. Later, realizing the benefits of forming a cooperative, particularly that of obtaining funds, MARCA members voluntarily agreed to registration as a processing cooperative.

With the registration, the cooperative met the requirements to receive support from the Countrywide Development Fund (CDF) for the processing facility. The registration and fulfillment of other requisites (including articles of cooperation, constitution and bylaws, seminar, and economic survey) also brought support from the Cooperative Development Authority (CDA). MARCA also received assistance in registering with the Department of Trade and Industry

Table 1. Components and methods used for processing and commercialization of cassava flour to Mabagon village, Leyte Province, the Philippines, 1991.

Component	Methods
Technical:	
Farmer-processors (for both equipment and processing)	Training, processing trials Informal team or group discussions Feedback Participant observation
Bakers	Training Baker-to-baker visits
Production:	Study or field visits
Farmers	Farmer-to-farmer visits
Organizational buildup and entrepreneurship development	Participant observation On-the-job training (e.g., in recording, inventory-taking, purchasing) Team buildup and group dynamics Specialized skills training (e.g., marketing, bookkeeping, accounting, and keeping financial records) Technical assistance (e.g., registration) Advisory discussions or consultations, formal meetings
Market development	Market research (unstructured, use of checklist-users' survey, feedback, contacting other markets) Researcher and farmer partnerships: (1) Expanding flour uses and testing markets (ready mixes with packaging and product testing) (2) Institutional collaboration for promotion (3) Byproduct use: coarse-grained flour in feed mix for swine (4) Integrated enterprise scheme
Monitoring and evaluation	Informal group discussions, field visits, meetings (MARCA team, local advisory group) Workshops Resident research assistant's logbook and diaries

(DTI), Bureau of Food and Drugs (BFAD), and a local nongovernmental organization.

Group buildup and entrepreneurial development

Building up entrepreneurial skills and strengthening the group were essential components for operational sustainability. These were carried out through:

Sessions on group dynamics. The first four sessions were designed to form values and attitudes that would condition individual members toward effective group endeavor. The remaining sessions concentrated on learning entrepreneurial skills, that is, planning, organizing, operational management, control, and evaluation.

Specialized training in entrepreneurship. Sessions were given in collaboration with the DTI. An initial, one-day, entrepreneurial appreciation session was conducted with emphasis on marketing skills. Other sessions included bookkeeping and marketing skills.

On-the-job training. During field and monitoring visits, researchers gave informal consultations and discussions on business management, marketing, recording, inventory-taking, product quality control, and equipment and facility maintenance. The resident research assistant gave a tutorial as part of the post's responsibility.

Workshops. Two workshops were conducted at the PRCRTC in August 1992 and March 1993. They were designed as learning exercises for MARCA members in presentation and analytical evaluation. The first workshop included MARCA and the other agencies involved in the project. The second was an attempt by the PRCRTC to encourage the different pilot project collaborators, and governmental and nongovernmental agencies to interact and learn from each others' experiences and to define their respective roles in this and other development programs.

Changes in the operational scheme

Cassava flour processing follows a decentralized operation where roots are chipped and dried to a specified quality by individual farmers, then sold to the plant. The chips are then milled and stored. MARCA distributes finished flour on a per order basis, once a week. The schedule, organization, and management of operational activities were made according to the members' time and ability.

Several changes resulted from members' experiences and feedback. For example, the daily shift for a three-member processing team was changed because some members were unavailable for family and work reasons. Starting January 1993, MARCA hired a regular processor who was paid ₱40.00 daily. The MARCA members took turns in assisting the regular processor. Each member was paid ₱35.00 daily.

Developing an integrated enterprise

The viability of the cassava flour processing enterprise is expected to evolve only gradually because of competition from wheat flour and the lag involved in learning to use cassava flour. MARCA needed to engage in enterprises related to its flour processing operations to solve liquidity problems, improve income, and enhance capacity as a market strategy. Thus, in 1993, the following operations were integrated into MARCA's business activities:

Trading. MARCA buys fresh roots from farmers and sells them to a starch plant situated about 80 km to the north. Trading is carried out from May to December when cassava drying is difficult because of the rainy season. Dried chips are bought during the dry season (January to April). Trading starts in the last week of November.

Operating a cooperative store to promote flour and feed. In November 1993, MARCA opened a village store (Mabagon is strategically located, serving mountain barangays) to sell flour, feed, and other cassava-based food products. Noncassava feeds for swine, such as the widely used base feed, were also sold to promote the MARCA feed mix, which had a higher protein content (14%-16% crude protein).

Market Development

Flour

The market target (25-30 bakeries, with a daily average total of eight bags, 10% cassava to wheat ratio) that would optimize plant use (4 t flour/month) was not reached within the first 6 months of operation. Only four bakeries were regular users and eight others were irregular, resulting in an average plant use rate of only 20%-30%.

The reasons for the slow penetration of the market were, first, learning how to handle cassava flour dough requires time, if both owner and baker are interested. If the price incentive was too low or the learning time too long, owners and bakers lost interest. Second, the number of bakers trained unexpectedly fell below target for the first 6 months. Third, the existing market used flour at a lower rate than expected (i.e., less than eight bags per day). Fourth, during the first year, the pilot project was still testing the stability of chip and flour quality, as well as test marketing, and an intensive marketing campaign was not being pursued at the time.

Given the results of this phase, the following marketing strategies were undertaken:

Visits and training. Consultation workshops, baker-to-baker visits, and training sessions were conducted to create the market for cassava flour. Twenty-five bakeries on Leyte Island were involved, from Maasin (about 45 km to the south) to Ormoc (about 80 km north). Visits between bakers gave them a chance to exchange ideas and experiences, and were more effective in transferring techniques and knowledge than was training. Because of the peculiarities in handling cassava-wheat composite flour, further market expansion will take time, as more training and exchanges are needed.

Market survey. The main constraints remained the lack of skills in using cassava flour for bread and the lack of price incentive. In 1993, cassava flour sales declined by more than 50%. From the informal market feedback, the nonsustainability of even the previous regular market may have been partly a result of the MARCA personnel's inadequate marketing efforts (Figure 1). This meant that the trainees needed intensive exposure and training during the remaining months.

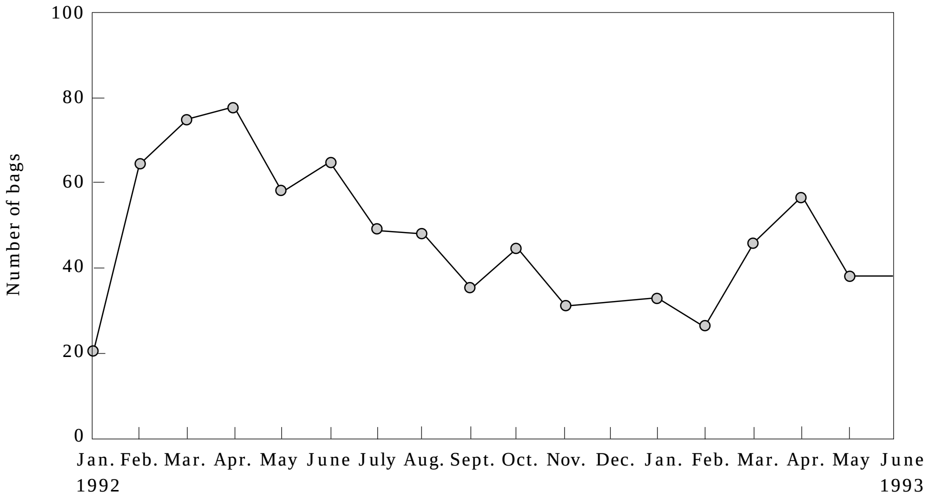

Figure 1. Sales of cassava flour in Mabagon village, Leyte Province, the Philippines, 1992/93.

Promotional posters for cassava flour. Initially, 150 promotional posters were produced with funding from the PRCRTC's extension program. These are now distributed in Leyte and Samar Islands and Surigao Provinces, and at the trade exhibits in the city of Cebu and at the Philippine Council for Agriculture and Resources Research and Development (PCARRD) at Los Baños (near Manila).

Testing other product ideas. Mixes with cassava-wheat composite flour were developed for the convenience food market. The 500-g packages, with recipes and an improved packaging design, was ready for promotion in November 1993.

Other markets explored. A distribution chain of native food products, with 150 outlets throughout the country and based in Manila, expressed interest in cassava flour. Samples of cassava flour, cassava meal (2 grades), and dehydrated cassava gratings were sent for testing. The cassava flour passed the quality test but the texture needed to be finer, to pass through a 60 mesh (down from the current 80). The dehydrated gratings were also acceptable and the firm is interested in placing an initial order. Grating equipment has been installed for processing and marketing trials for the first quarter of 1994. The cassava meal was unacceptable for ready mixes.

Processing other food products from cassava flour

To expand the market for cassava flour, MARCA members were trained in food processing. Three training sessions on various food products from cassava flour and fresh roots were conducted for MARCA members, one at Visayas State College of Agriculture (ViSCA) and two at the site. Because of a more promising market, MARCA decided to concentrate on *cacharon* and *polvoron*. The equipment is made and processing trials are expected to start during the first quarter of 1994.

Use of byproducts: cassava meal

Markets for cassava meal were explored. The flour is made into a native delicacy (*ira-id*) but the market is limited. About 2,000 kg of cassava meal were also sold to the ViSCA feed mill at ₱3.50 per kg. But this market is unstable.

A more promising venture is to use cassava meal in swine feed mix. The ration was market tested in outlets in the nearby towns of Hindang and Hilongos. The formula contains about 15%-16% crude protein, as tested by the PRCRTC Laboratory. The price was competitive, being only about 72% of that of the popular base feed for swine.

The MARCA feed mix is made from pre-mix, and meals of cassava, fish, copra, and ipil-ipil leaves. Local women and children supply the leaves (Table 2). Profitability ranged from ₱0.50 to ₱0.75 per kg, depending on the sources of protein used. Other mix combinations, including *kohol* (a snail), will be tried out to determine the most efficient mix.

A plan is under way to promote the feed mix by integrating into MARCA's operations the sale of complementary feeds, such as the swine base feed, which farmers commonly use.

Machine Evaluation and Improvement

Flour finisher

The first finisher brought to the site was a manually operated machine with a capacity of 20-40 kg/h when

Table 2. Formula of a feed mix for swine, and costs. The mix was made by a cassava processing cooperative in Mabagon village, Leyte Province, the Philippines.

Ingredient or input	Weight (kg)	Crude protein content (%)	Cost (₱)
Cassava meal	52.10	1.0	208.40
Copra meal	24.00	5.3	120.00
Fish meal	9.00	5.4	90.50
Rice bran	8.50	1.0	25.50
Ipil-ipil leaf meal	4.15	0.9	12.45
Golden snail	1.50	0.3	6.00
Salt	0.50		2.50
Afsillin	0.25		29.00
Labor			30.00
Bags			6.00
Transport			10.00
Total	100.00		540.35[a]

a. Cost of feed mix per kilogram = ₱5.40; wholesale price = ₱6.50/kg; retail price = ₱7.00/kg.

tested at the PRCRTC. But when used by the farmer-operator, it did not perform as expected. The flour clogged the screen, barely flowing out of the finisher. This was withdrawn and a temporary, manual one used until a new one was designed and made.

Motor-operated, the new finisher had a fan which forced the fine flour to pass through the screen. This machine had a higher capacity than the old one: at least 50 kg/h in a single pass. The cooperative's members used it until another, improved, machine was made, based on farmer-operators' evaluations.

The design now used has two main improvements: the feeder hopper was enlarged to accommodate a larger flour volume, and a metering device was mounted. These modifications improved the operation's efficiency by removing the tedium of manually feeding and frequently stirring the ground chips in the hopper. They also reduced finishing time by about 50%.

Portable chipper

A portable chipper introduced to the cooperative was expensive for the members, having an estimated cost of ₱500. In contrast, the *andolan*—a local chipper made from a perforated GI sheet mounted on a piece of wood—costs about ₱15.00 per unit. The chipper was therefore not cost effective for individual households, because of the very small scale of home processing. The portable chipper also had to be mounted for the operator's convenience.

However, the expected advantages of the portable chipper are an increased yield of chips and eliminated risk of abraded hands while processing. Cost-sharing among households may make the chipper more cost attractive.

Modified* tapahan *dryer

Dryers were used only during the rainy season, when sun drying was impossible and orders for flour had to be satisfied.

A dryer was constructed on site and tested. In the first two tests, it was too heavily loaded (463 and 200 kg of fresh chips), and the mixing turned the chips brown and hence unsuitable for flour production. In the third test, the chips were not mixed and their color was more acceptable for flour production. In the fourth test, the farmers evaluated the dryer, loading it with 190 kg of chips. The chips were not mixed, and dried in about 12 h. Their color was lighter than in the third test.

Improving Cassava Production Systems

Although the issue of environment friendly cassava production on sloping land was raised during informal discussions with farmers, it became a pressing concern with increasing commercialization. The issue of sustainability of cassava production and processing systems became integrated into the project.

Two groups of cassava farmers from Hindang visited farming-system projects in Matalom, where model contour farms were shown. The farms had cropping systems similar to those of Mabagon and other cassava-producing communities. Farmers discussed the benefits of contour farming and the disadvantages of irresponsible farming. After two visits, seven model contour farms were set up in Hindang. These are still being followed up.

Project Management: Monitoring and Evaluation

Interdisciplinary team approach

Active interaction among team members was tried informally during field visits and discussions, and formally through monthly meetings. Although the independent contribution of each discipline was valuable, team members were constrained by having other responsibilities.

Resident research assistant

Living in the village enabled the resident research assistant to observe social behavior and norms. The assistant had to observe, facilitate, train, and catalyze the farmers, and monitor results in logbooks or diaries. The assistant left the village in July 1993 as farmers took over the flour production project.

The local advisory group

This interagency group consisted of local government representatives, the DTI officer, a technician from the Department of Agriculture, and representatives from the village and the farmers' group, MARCA, and the PRCRTC. The local advisory group was to build up local management capability and to continue assisting MARCA after the PRCRTC left Mabagon in March 1994.

Monitoring and evaluation

These were done, first, by the team, based on observations from market surveys, field visits, and notes and feedback from the resident research assistant; and, second, through MARCA's regular monthly meetings, and informal discussions with, and feedback from, MARCA. Farmer participation was always encouraged. Findings and observations were used to plan, modify, and improve the execution of activities.

Some Impact Indicators

An important objective of the project was to assess the acceptability and adoptability of introduced technologies and their effects on processing and on farming households (Table 3).

Table 3. Acceptability and adoptability of introduced technologies for cassava flour production in Mabagon village, Leyte Province, the Philippines.

Technology	Acceptability and/or adoptability
Machines:	
Pedal-operated chipper	Power efficient, acceptable, but of limited use. Most processors prefer the local *andolan*.
Grinder and finisher	Acceptable, adopted. Easily learned. Modifications to enhance the grinding and finishing capacities.
Modified *tapahan* dryer	Acceptable, but not adopted. Costly to use. Sun drying with plastic mats produces better quality flour more efficiently.
Portable chipper	Initial testing. Not acceptable. Design being improved.
Bulk storage in polyethylene bags	Acceptable. Adopted.
Processing:	
Flour processing	Adopted. Needs market expansion and promotion.
Swine feed mix	Adopted. Needs market expansion and promotion.
Food processing: cakes, doughnuts, *siakoy* [a]	Accepted. Not adopted. No facilities, and difficulties in operation.
Cacharon [b]	Acceptable. Promising market. In the process of fabricating equipment.
Polvoron [a]	Acceptable. Adopted by individuals. Planned for enterprise.

a. *Editors' note:* No description of this product was provided by the authors.
b. *Cacharon* is a puffed product with various flavors.

Organizing and entrepreneurial skills

Markedly satisfactory performance was observed in terms of growth in cooperation, improved attitudes, processing skills, and enterprise management. It was also evident in group work, attendance at meetings, assemblies, workshops, participation in discussions, and carrying out of assigned responsibilities in operations and marketing.

Enterprise diversification

MARCA is learning to integrate related enterprises to make operations more viable and profitable. An "entrepreneurial" culture at the village level is gradually evolving.

For the first 5 months of operation, at 30% capacity, the net profit per kg of fine flour was ₱0.61. With 90% capacity, this could improve to ₱1.50/kg. If cassava meal is included, net profit per kg is 1.04 at 30% capacity and ₱1.79 at full (Table 4). Financial statements (Jan.-Dec. 1992) show that, during the year's operation, profitability decreased because plant use dropped to 20% (see Appendix). The enterprise's profitability was improved with the use of cassava meal in feed mix. Profit per kg ranged from ₱0.50 to ₱1.10, depending on the ingredients used, which, in turn, were chosen so to obtain a feed mix price that was ₱2.50 lower than the popular, base feed brand.

Table 4. Cost and returns for cassava flour per month per capacity use in a flour plant at Mabagon village, Leyte Province, the Philippines. Assumptions were: fine flour yield = 85%; full capacity = optimal flour production for 120-h week; cost of chips = ₱4.00/kg; price of fine flour = ₱8.00/kg; price of cassava meal = ₱3.50/kg.

Cost and return per capacity use	1.2 t/month (15 bags/week) at 30% capacity	4 t/month (50 bags/week) at full capacity
Flour	9,600.00 (1,200 kg)	32,000.00 (4,000 kg)
Less costs for:		
Chips	5,647.00 (1,411.75 kg)	18,823.53 (4,705.88 kg)
Labor	1,577.45	3,154.90
Electricity	135.95	543.80
Marketing costs	271.60	1,086.40
Bags	300.00	1,000.00
Depreciation costs	937.00	1,405.50
Total costs	8,869.00	26,014.63
Net profit (fine flour)	731.00	5,985.87
(per kg)	0.61	1.50
Cassava meal sales	741.16 (211.76 kg)	2,470.58 (705.88 kg)
Total monthly income	1,472.16	8,456.45
Overall net profit per kg	1.04	1.79
Cost per kg of fine flour	7.39	6.50

Multiplier effect on the community

Market and income. From January to December 1992, MARCA bought from the farmers a total of 20 t of cassava chips, costing, in total, ₱73,921.00. This contribution to farmer income was substantial, compared with the chips market before MARCA, in which only about 5 t/year were sold, assuming an average of 3.5 bags/week. Farmers in Mabagon, Himacugo, Katipunan, and Baldoza are some of MARCA's suppliers.

Improved chip quality. The quality (whiteness, aroma, and brittleness) of home-processed chips improved markedly, conforming to the desired moisture content (12%-14%). Proof of this was that flour quality stabilized.

Supplementary income via wage employment and other social benefits. Members derive satisfaction from earning even a minimal wage by working at the plant. They also feel a sense of achievement from learning new skills and being active in an enterprise—stimulated by motivation, pride, and hope that not all government projects fail. The buildup of entrepreneurial spirit, strengthening local institutions, and improvement in people's organizational performance and attitudes are benefits which are difficult to measure. Yet they are essential for rural mobilization and growth. The processing plant became a source of prestige to the community, and gave farmers confidence that they could achieve even more.

Conclusions and Recommendations

The approach

This exploited the skills of, not only different kinds of researchers, but also of the beneficiaries themselves. The participatory process eventually gave the farmer-processors a sense of achievement: that through interactive, informal discussion with researchers they could make effective decisions. Such “ownership” of achievement is key to the buildup of capacities, which can only be achieved through gradual experiential learning.

Local people’s involvement in project management also eased the task of team members who were constrained by time and resources. Local agencies shared responsibilities. Once the project ends, their familiarity with it will enable the locals to continue managing the established enterprise.

Defining the focus and making the project small and simple intensified technology learning and enabled the processors to stabilize product quality.

Participatory observation helped discover social processes and interrelationships, facilitating the modification or redesign of introduced technologies. Behavior and attitudes are central concerns in the process of technology transfer, preconditioning technology adoption. The project also facilitated on-the-job learning of technical and entrepreneurial skills. Placing a qualified resident research assistant in the field significantly facilitated technology transfer.

Technology viability

The commercial viability of cassava flour processing depends largely on intensifying the farmers’ understanding of cassava flour use and market expansion. Currently, commercial cassava flour production is not viable without integrating the commercialization of byproducts, expanding end uses of flour as, for example, a raw material in other products and food processing, or trading related complementary products. To encourage farmers to set up a successful enterprise therefore requires a carefully integrated plan, in which each step, made small, simple, and focused, is gradually introduced. The step-by-step process would help farmers understand that every product or additional activity needs a minimal standard of quality, stable supplies, good service, and competitiveness.

A pilot and commercialization project should therefore have the institutional or external support for investment in market research and promotion because farmer groups usually do not have the needed funds to start up marketing activities.

Institutional flexibility

The research team members must be sensitive if they are to successfully collaborate in arranging development activities in such a way that the project has technical, marketing, economic, and operational viability. From the beginning, team members must understand the need for such sensitivity even in the planning process. The project’s success depends on the ability of the team and farmers to respond to changes, and modify plans and strategies to achieve objectives. Planning then becomes an iterative process. But being responsive to uncertainties can be demanding on the team, which demands, if not addressed, may cause delays or even failures.

This implies that some degree of institutional flexibility is needed in teaming up and distributing workloads to ensure that researchers have adequate time to undertake the responsibilities involved in a "commercialization" project. These responsibilities are based on the implications of the integrated process approach: a commitment to (1) using participatory research methods, and (2) ensuring interactive learning between farmers and researchers.

The integrated approach also assumes the availability of a minimum, adequate, institutional support to permit the exercise of the two basic responsibilities and provide the support services needed to make the project work. The policies of the participant institutions should thus be geared toward making the integrated approach work.

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Appendix

Financial statements for the period January to December, 1992, of the Mabagon Root Crop Association (MARCA), a cassava processing cooperative at Mabagon village, near the town of Hindang, Leyte Province, the Philippines.

Statement A. Flour processing: the cost of goods manufactured (Jan.-Dec. 1992 operation)

Item	₱
Materials used	
Beginning raw material inventory (chips)	0
Plus purchases	73,921.00
Cost of raw material available for use	73,921.00
Less ending raw material inventory	1,196.00
Cost of raw material used	72,725.00
Plus other raw materials used (fresh roots)	2,720.00
Total cost of raw materials used	75,445.00
Direct labor	14,570.00
Factory overhead	12,816.05
Total manufacturing costs	102,831.95
Less cost of goods in process inventory	0
Cost of goods manufactured	₱102,831.95

Statement B. Flour processing: income statement for Jan.-Dec. 1992.

Item	₱
Sales	
Flour	98,930.25
Cassava meal	15,558.55
Damaged chips	1,365.50
Total sales	115,854.30
Cost of goods sold	
Beginning finished goods inventory	0
Cost of goods manufactured	102,831.95
Total costs of goods for sale	102,831.95
Less ending flour inventory	2,759.45
Cost of goods sold	100,072.50
Gross profit on sales	15,781.80
Less selling expenses	
Delivery personnel	900.00
Packaging	1,366.00
Transportation	3,983.00
	6,249.00
Net income from operation	₱9,532.80

Statement C. Chips trading operation: income statement.

Item	₱
Sales	7,017.65
Cost of goods sold	
Beginning inventory (chips for feed)	0
Plus purchases	6,412.50
Cost of goods available for sale	6,412.50
Less ending inventory of chips	235.50
Cost of goods sold	6,177.00
Gross profit on sales	840.65
Less purchasing expenses	50.60
Net profit from operation	₱790.05

Statement D. Balance sheet: feed mix operation at end of December 1992.

Item	₱
Assets	
Cash	533.45
Accounts receivable	1,542.25
Inventory	1,471.30
Total assets	3,547.00
Liability	
Accumulated profit	3,547.00

Statement E. MARCA balance sheet for the year ending December 1992.

Item	₱
Assets	
Cash	
Flour and chips operation	11,206.20
Feed mix operation	533.45
Registration fees	340.00
Chipper rent collection	130.15
Bank account	33,437.15
Accounts receivable	
Flour and chips operation	2,031.50
Feed mix operation	1,542.25
Inventory	
Flour and chips operation	4,190.95
Feed mix operation	1,471.30
Supplies and materials purchased	
Drying mats	950.00
Fluorescent tube	152.00
Buildings and warehouse	10,434.10
Electricity installation	333.65
Processing machines	50,958.65
Total assets	117,711.35
Liabilities	
Accounts payable	789.75
Accumulated depreciation	9,843.75
Loans: SEARCA[a]	5,000.00
Others	23,497.60
Processing machines	50,958.65
Owners' equity	
Labor capital raised	14,559.25
Profit from operation	13,869.85
Less bank charges	75.00
Wall clock	189.50
Registration expenses	93.00
Drying mats	450.00
	-807.50
Total liability and owners' equity	117,711.35

a. SEARCA = Southeast Asian Regional Center for Graduate Study and Research in Agriculture.

CHAPTER 41

DEVELOPING THE CASSAVA FLOUR INDUSTRY IN RURAL AREAS OF INDONESIA

*A. Setyono**, *Sutrisno**, and *D. S. Damardjati***

Abstract

Increasing cassava production and developing the technology for cassava processing involve tackling problems in such areas as technology, productivity, marketing price stability, and production continuity. Once harvested, cassava is perishable, that is, the roots are of acceptable quality for only a few days, creating a major problem for farmers who are thus in a low bargaining position. Cassava flour is one way of overcoming this problem.

This study aims to (1) develop the cassava flour industry at three levels, (2) increase cassava's added value and thus farmer income, and (3) develop this industry in rural areas.

Three levels of development of the cassava flour industry were attempted in rural areas. The first was at the level of the individual farmer, where farmers' activities included cassava flour production, marketing of cassava flour, and processing and marketing flour-based products. The second was at the farmer group level, where farmers worked together to produce cassava flour, market it, and process and market flour-based products. The third was at the cooperative level, where the cooperative village unit (Koperasi Unit Desa) collects cassava flour from farmers and farmer groups, and then sells it to the retail trade and food industry, the feed industry, and other consumers.

Results indicated that marketing was a major problem in Central Java's cassava flour industry. Cassava flour use and its processing technology have not yet developed. The cassava flour industry has little knowledge of and experience with marketing, which hinders development. The industry can be developed in rural areas only through the cooperative system, or the farmer group system, if given support in developing processing technology and household industry, and in obtaining processing equipment and machinery.

Introduction

Cassava (*Manihot esculenta* Crantz) is the most important staple food crop after rice and maize in Indonesia. At present, farmers cultivate cassava in almost all areas of Indonesia, from lowlands to highlands, in dry or wet

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climates, and under various soil conditions. Table 1 summarizes the use of upland areas in Indonesia. Wargiono (1988) stated that the harvested area of cassava in Indonesia showed a decreasing trend of 0.7% per year. But since 1986, the trend has increased slightly and, in 1991, the total harvested area was about 1.3 million hectares, with a total production of almost 16 million tons (Table 2). Cassava's production rate from 1969 to 1985 was 2.05% per year (Affandi, 1986).

Thirteen of Indonesia's provinces (Table 3) are major cassava-producing areas, each province having more than 10,000 ha under cassava (Pabindru, 1989). The average yield per ha is low at 10-12 t/ha. This can be increased by introducing new technologies to farmers such as improved varieties and cultural practices. On a cassava estate owned by a tapioca factory in Lampung, yields of 25-30 t/ha have been continuously achieved (Rusastra, 1988).

Table 1. Summary of use of upland areas (ha) in Indonesia, 1984-1987.

Kind of upland	Year			
	1984	1985	1986	1987
Cultivated (permanent basis)	8,327,282	8,091,282	8,377,480	8,761,476
Cultivated (temporary basis)	2,950,485	2,826,683	2,902,528	3,125,278
Unused or uncultivated	7,371,511	7,409,646	8,097,646	8,320,418
Total	18,649,278	18,327,611	19,377,654	20,207,172

SOURCE: SFCDP, 1990.

Table 2. Harvested area, production, and yield rate of cassava in Indonesia, 1984-1992.

Year	Harvested area (000 ha)	Production (000 t)	Yield rate (t/ha)
1984	1,350	14,167	10.5
1985	1,292	14,057	10.9
1986	1,170	13,312	11.4
1987	1,222	14,356	11.7
1988	1,302	15,471	11.9
1989	1,408	17,117	12.2
1990	1,312	15,830	12.1
1991	1,319	15,955	12.1
1992[a]	828	10,221	12.3

a. Preliminary data.

SOURCE: CBS, 1992.

Table 3. Production and yield per hectare in cassava-producing provinces of Indonesia, 1991.

No.	Province	Production (000 t)	Yield rate (t/ha)
1.	North Sumatra	337.7	12.4
2.	South Sumatra	407.8	12.2
3.	Lampung	1,828.2	12.7
4.	West Java	2,129.0	13.3
5.	Central Java	3,313.4	12.1
6.	Yogyakarta	680.7	11.3
7.	West Java	3,718.2	12.6
8.	Bali	260.5	13.5
9.	Maluku	223.9	10.8
10.	Northern Territory	763.3	10.3
11.	West Kalimantan	264.1	9.9
12.	South Sulawesi	483.1	11.6
13.	Southeast Sulawesi	996.7	11.3

SOURCE: CBS, 1991.

Problems of Developing the Cassava Agroindustry

These are cassava's association with low social status; inadequate marketing, postharvest handling, processing, and cultural practices; and low productivity.

Association with social status

Most Indonesians consider cassava as a food for those of low socioeconomic status. When income increases, then consumers switch from cassava to rice. Cassava consumption per capita per year has tended to decrease gradually in Indonesia, dropping from 57.4 kg per capita in 1983, through 51.0 kg per capita in 1988, to 43.1 kg per capita in 1990 (Table 4).

Marketing

Most cassava in Java is used for human consumption or starch (tapioca). Cassava farmers near starch factories usually sell fresh roots directly to the factories, while those in remote areas tend to first process cassava into *gaplek*, or dried cassava chips, and then sell to middlemen, who transport and sell the chips to exporters or pelleting factories in urban areas. Farmers in Java sell about 50% to 90% of their fresh cassava roots to traders or middlemen.

Farmgate prices of cassava fluctuate between Rp (rupiahs) 26 and Rp 177/kg, according to location and harvesting time (Tjahjadi, 1989). Cassava is also perishable, and often cannot be processed or consumed immediately after harvest. These problems limit the flexibility of cassava and force farmers into a low bargaining position.

Postharvest handling and processing

Cassava is usually harvested manually, and may suffer severe damage if the roots are not carefully dug out of the ground. Roots deteriorate rapidly after harvest, and are bulky, making transportation difficult and expensive.

According to the Indonesian food balance sheet data (CBS, 1992), total cassava production in 1991 was 15.8 million tons (Table 5). Of this, 56.0% was consumed fresh or as *gaplek*; 15.7% was exported as *gaplek* (chips), pellets, and tapioca; and 20.3% was used as raw material in industries such as tapioca (starch)

Table 4. Average per capita consumption of major food crops in Indonesia, 1983-1990.

Commodity	Per capita annual consumption (kg)[a]					
	1983	1986	1988	1989	1990	1991
Rice	145.21	147.36	150.18	140.84	150.05	145.53
Cassava	57.41	51.49	51.00	51.41	43.07	48.87
Tapioca	0.50	1.35	1.00	-	-	-
Gaplek[b]	-	-	1.46	-	-	-
Sweetpotato	12.46	11.05	10.93	11.04	9.74	9.61
Wheat	8.19	5.96	6.59	6.93	7.54	7.71
Maize	27.35	29.25	30.75	26.81	29.68	28.73
Soybean	4.45	8.80	9.49	8.80	10.72	11.01

a. - = data not available.

b. *Gaplek* = dried cassava chips.

SOURCES: CBS, 1991; 1992.

Table 5. Trends in production and use of cassava in Indonesia, 1987-1991. No data were available for exports or nonfood industries. (Values in parentheses refer to percentages rounded off.)

Production or use	Fresh roots (or equivalent) (thousands of tons)				
	1987	1988	1989	1990	1991
Total production	14,356	15,471	17,117	15,830	15,813
Waste	1,866 (13)	2,011 (13)	2,225 (13)	2,058 (13)	2,056 (13)
Manufactured for:					
Feed	287 (2)	309 (2)	317 (2)	317 (2)	316 (2)
Food industry	3,401 (24)	4,288 (28)	5,781 (37)	5,781 (37)	4,583 (29)
Food consumption	8,802 (61)	8,863 (57)	7,674 (48)	7,674 (48)	8,858 (56)

SOURCES: CBS, 1989; 1991; CBS, 1990, personal communication.

(7.9%) manufacture and nonfood industries (12.4%). Postharvest losses are relatively high, about 13.0%.

Cassava roots can be used in various forms: fresh roots are cooked (boiled, roasted, steamed, or fried); fermented to produce *tape*; dried (either whole root, slices, or chips) to produce *gaplek*; extracted to produce tapioca (starch); or the *gaplek* milled to produce flour. *Gaplek* can be kept as a food reserve or as animal feed. In villages of Java, most cassava is used for human consumption, and many traditional products are produced for local and national consumption.

Cassava as a marginal crop

Farmers tend to grow cassava with traditional, sometimes inadequate, technology. Being a crop with unstable prices (a consequence of undeveloped processing technology), cassava is often grown in fragile soils with little or no investment in fertilization.

Study Objectives

Our study aimed to (1) improve postharvest handling of cassava by farmers, (2) introduce and develop cassava flour production and the processing of flour into other products, and (3) develop household and small-scale cassava processing industries in a village of Central Java.

Materials and Methods

Research took place in Kejobong Subdistrict, Purbalingga District, Central Java Province, during 1991-1993. It was conducted in three phases: surveying, introducing cassava flour production and processing technology, and evaluating the development of the cassava flour industry.

Surveying cassava postharvest handling and processing

A survey was carried out in Purbalingga District, from May to June 1991. Primary data was collected from farmers on how they handled cassava after harvest, processed the roots, and marketed their products. A literature search was also conducted on cassava production, area of land use, and cassava processing in Purbalingga District. From all these data, we chose the experimental site.

Introducing cassava flour production and processing technology

The second phase, that of introducing new cassava flour production technology and processing, was conducted from August 1991 to March 1992.

Evaluating the development of the cassava flour industry

The development of the cassava flour industry in Kejobong Subdistrict was evaluated during June to September 1993. The evaluations were at individual, group, and cooperative levels in rural areas, including cassava flour entrepreneurs. Production, processing, marketing, and other problems were also assessed.

Results and Discussion

Survey results

Socioeconomic conditions of Kejobong Subdistrict. Table 6 summarizes land use in Purbalingga District. Land use in Kejobong Subdistrict is divided as uplands (about 84%), lowlands (4%), and degraded lands (12%) (Table 7). Altitudes range from 70 to 100 m above sea level, climate is type A, and annual rainfall is 4,048 mm (Table 8).

Total population in Kejobong Subdistrict was 66,712 (32,622 males and 34,049 females). Most people in Kejobong derived their income from agriculture: 40% from food crops, fishery, and cattle raising; and 4% from other agricultural work. The rest worked in industry (7%); retail

Table 6. Summary of land use (ha), by subdistrict, in Purbalingga District, Central Java, Indonesia, 1983.

Subdistrict	Lowlands	Uplands	Degraded lands	Total
Bukateja	2,103	2,137	-	4,240
Kejobong	361	7,811	1,090	9,262
Kaligondang	1,121	3,932	1,212	6,265
Kemangkon	2,311	2,203	-	4,514
Purbalingga	798	676	-	1,474
Kalimanah	2,928	1,049	-	3,977
Kutasari	2,377	5,833	310	8,520
Bobotsari	1,275	1,953	311	3,539
Mrebet	1,607	3,182	924	5,713
Karangrejo	1,295	10,785	795	12,875
Karanganyar	2,414	4,422	290	7,126
Karangmoncol	1,609	4,419	1,068	7,096
Rembang	2,007	7,152	3,372	12,531
Total	22,204	55,554	9,372	87,130
Percentage[a]	25	64	11	100

a. Values are rounded off.

Table 7. Summary of land use in Kejobong Subdistrict, Central Java, Indonesia, 1983.

Type of land use	Area	
	(ha)	(%)[a]
Lowlands:		
Technical	166	2
Semitechnical	31	<1
Simple	16	<1
Rainfed	148	2
Total	361	
Uplands:		
Building and garden	3,224	35
Cultivated (temporary basis)	4,332	48
Other	225	3
Total	7,781	
Degraded lands	1,090	12
Overall total	9,232	

a. Values are rounded off.

Table 8. Monthly rainfall and number of rainy days per month, averaged over 9 years, Purbalingga District, Central Java, Indonesia, 1981-1989.

Month	Monthly rainfall (mm)	Number of rainy days per month
January	481	19
February	484	20
March	436	19
April	418	19
May	236	12
June	181	10
July	137	8
August	105	7
September	256	11
October	336	15
November	493	18
December	483	20
Total	4,046	178
Av./month	337	15

(4%); transport (<1%); government (1%); and others (<1%). About 2% of employed were not reported (Table 9).

Kejobong is the major center of cassava production in Purbalingga District. Production was 43,671 t in 1986 (Table 10).

Harvesting, and postharvest handling and processing

Harvesting. Two major varieties of cassava are planted in Kejobong: the bitter 'Klanting' (90%) and the sweet 'Darme' (10%). Harvesting is usually by hand during August to November. Of 36 respondents in seven villages, 7 harvested the cassava themselves, 6 paid others to harvest, 4 harvested through the cooperative system, 17 had sold the harvest in advance, and 2 did not harvest.

Postharvest handling and processing. Postharvest handling and processing of cassava have not yet developed in Kejobong, because most farmers sell cassava as fresh roots. Only about 30% of farmers process cassava, producing such traditional goods as *gaplek*, *tiwul*, and *cantir*. Only 5% of farmer-processors produced tapioca (Table 11).

The farmers either sold peeled cassava to middlemen (50%) and retailers (8%), or were paid in advance before harvest (42%). Because the total potential capacity of factories

Table 9. Population by livelihood, Kejobong Subdistrict, Central Java, Indonesia, 1986.

Source of livelihood	People (no.)	(%)[a]	Remarks
Agriculture:			
Food crops, fishery, and cattle raising	26,614	40	
Other agricultural work	2,392	4	Agricultural laborer
Industry and Services	4,995	7	Entrepreneur or employer
Retail trade	2,895	4	
Transportation	133	<1	
Government	814	1	Functionary, laborer, army worker, pensioner
Others	378	<1	
Unreported	1,538	2	
Total employed	39,759	60	
Total population	66,712		

a. Values are rounded off.

Table 10. Total production (t) of food crops in Purbalingga District, Central Java, Indonesia, 1986.

Subdistrict	Lowland rice	Upland rice	Maize	Soybeans	Groundnuts	Sweet-potato	Cassava
Bukateja	18,023	17	133	151	221	-	2,047
Kejobong	2,604	2,134	14,435	67	239	-	43,671
Kaligondang	7,810	-	925	143	221	-	4,513
Kemangkon	23,850	1,082	1,898	426	256	34	970
Purbalingga	8,118	-	226	79	103	-	34
Kalimanah	28,694	-	921	285	241	29	21
Kutasari	16,046	1,931	6,805	143	672	714	5,657
Bobotsari	8,958	-	1,636	106	35	126	1,223
Mrebet	15,670	-	1,285	142	263	49	1,824
Karangrejo	3,073	-	2,357	130	-	435	3,244
Karanganyar	19,281	385	1,092	96	-	53	3,044
Karangmoncol	5,095	-	226	53	-	-	176
Rembang	9,804	91	1,052	80	3	224	5,422
Total	167,026	5,640	32,991	1,901	2,254	1,664	71,846

Table 11. Percentage (values rounded off) of respondents (farmers) who process cassava, and their products, Kejobong Subdistrict, Central Java, Indonesia.

Product	Respondents
Gaplek (dried cassava chips)	17
Cantir[a]	8
Cendol[a]	3
Tiwul[a]	3
Tapioca	5
Cassava flour	0
Total	31

a. *Editors' note:* No description of this product was provided by the authors.

was equivalent to 12,092 t of fresh cassava (i.e., 2,423 t of tapioca) (Table 12), the total cassava production of 71,846 t could not be processed. Consequently, cassava prices fell, fluctuating according to retailer or tapioca factory. In 1989, the price of cassava ranged from Rp 25 to Rp 30/kg.

But after cassava flour processing was introduced, the price of cassava rose from Rp 50-60/kg in 1990 to a peak in 1991 and 1992 at Rp 90-115,

Table 12. The capacity of tapioca factories in Purbalingga District, Central Java, Indonesia, 1989.

Manufacturer	Subdistrict	Started operations	Potential capacity (t/year)	Operational capacity (t/year)
Lamuk	Kejobong	1983	8	8
Pandansari	Kejobong	1987	75	60
Wanakusuma	Kejobong	1988	720	600
Sribumikarya	Kemangkon	1988	720	600
Tridaya	Bukatiga	1988	900	900
Total			2,423	2,168

and dropped slightly to Rp 70-80 in 1993. Two years ago (i.e., 1991/92), the production of cassava flour was not profitable, because the cassava flour price ranged from Rp 350 to Rp 400/kg.

Cassava flour production involves several processing steps: peeling, washing, slicing or rasping or chipping, pressing, drying, and milling (Figure 1). These new technologies were introduced, by demonstration, to farmers, farmer groups, and members of the Village Unit Cooperative, or Koperasi Unit Desa (KUD). These people assessed the technologies and were then trained in their use. Cassava flour is used to substitute wheat flour in the making of such foods as pancakes, cookies, cheese sticks, and *putu ayu*.

The cassava flour industry was developed in rural areas as a three-level system (Figure 2). On the first level, the individual farmer produced cassava flour, and processed and marketed it himself. On the second level, the farmer group performed these activities. On the third level, the KUD not only produced cassava flour, but also received it from farmers or farmer groups, and then sold it to food industries and middlemen.

Cassava Flour Production and Processing Development

The objectives of this development project were to (1) encourage the production and processing of cassava flour by individual farmers and farmer groups, and (2) increase the added value of fresh cassava by processing it into flour. The project was conducted in three phases.

Introducing cassava processing equipment

Processing equipment was demonstrated to farmers to arouse interest in cassava flour production, encourage an increased working capacity and product quality, and promote the development and manufacture of processing equipment in rural areas. The equipment introduced and demonstrated included slicers, carvers, graters, and presses.

The Kejobong KUD, in particular, received, from the Government, equipment with a daily capacity to process 10 t of cassava roots into flour.

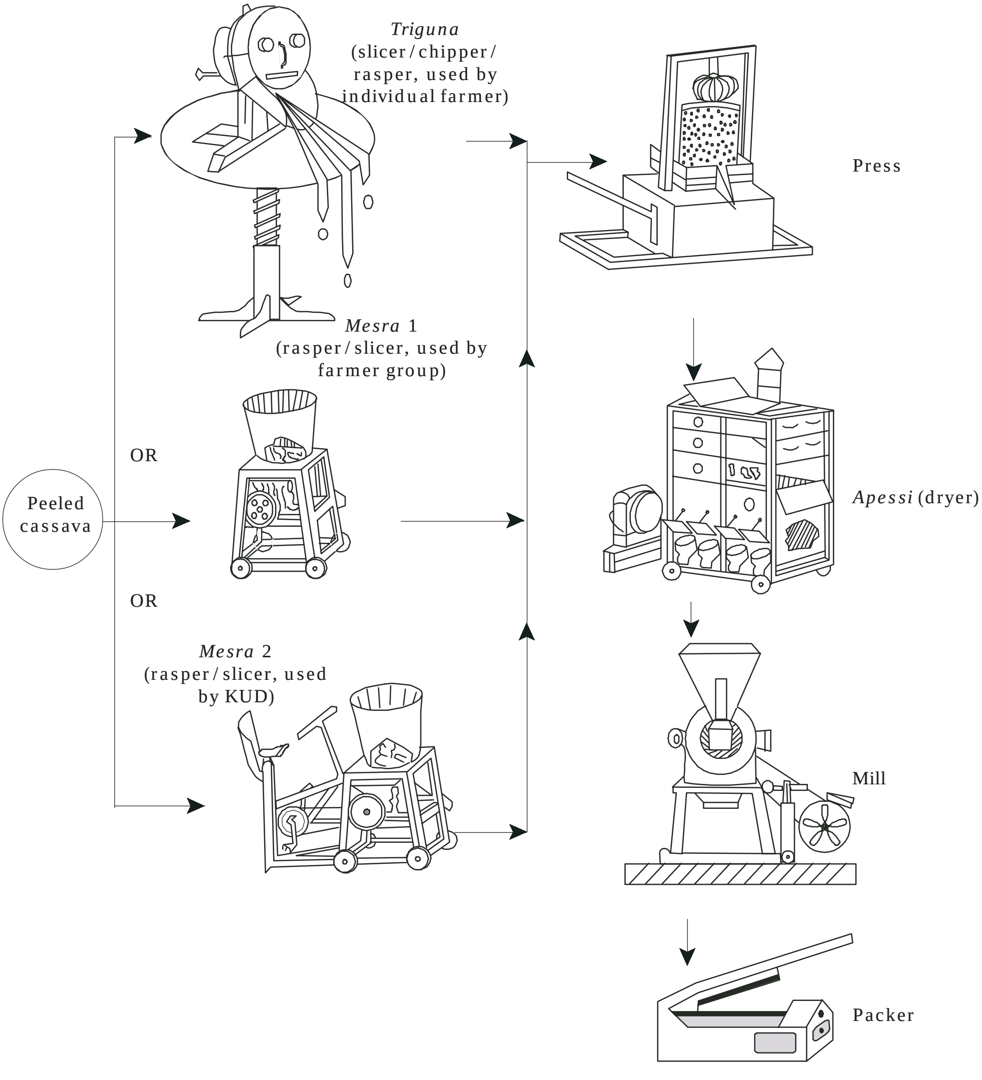

Figure 1. Cassava flour production in Kebojong Subdistrict, Central Java, Indonesia. (KUD = Village Unit Cooperative.)

Cassava flour production

Flour production would help sell cassava when prices are low and demand from tapioca factories is also small.

In 1992, individual farmers produced about 300 kg of cassava flour, which was processed to cookies and pancakes. Farmer groups produced 1 t of cassava flour and cooperatives 5 t. They sold it to food industries and middlemen. The major problems of cassava flour production at all three levels were found in marketing.

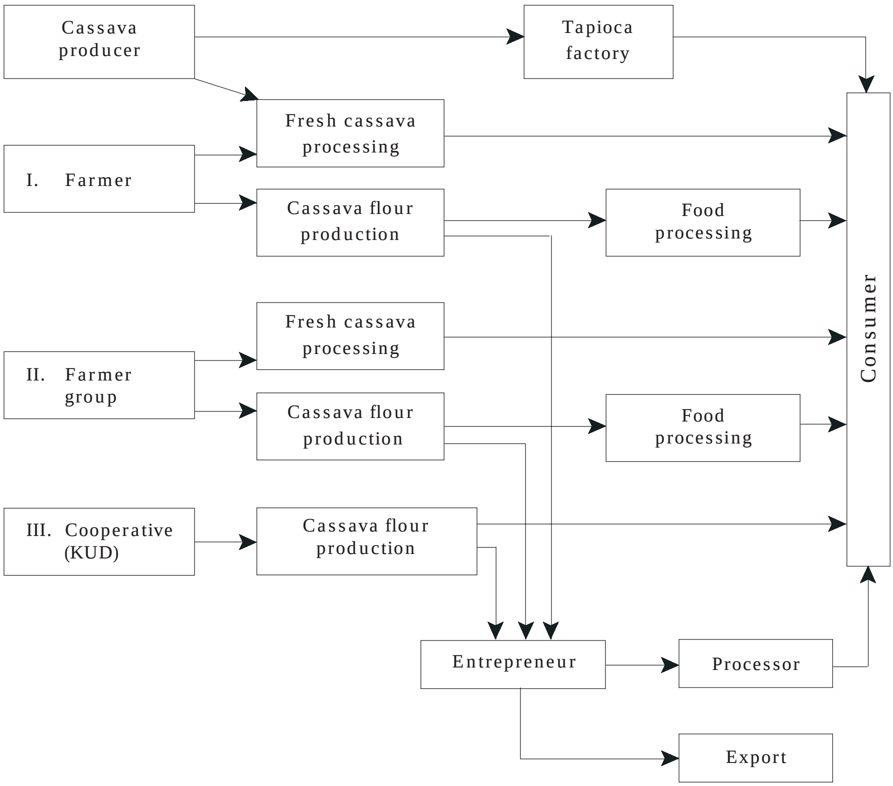

Figure 2. Developing an agroindustry based on cassava flour production in rural areas of Indonesia. (KUD = Village Unit Cooperative.)

Food technology and cassava flour use

Marketing and food technology are important in the successful development of a cassava flour industry. Successful marketing is influenced by product utility and requisites for quantity and quality. Developments in food technology increases opportunities for marketing cassava flour. Outlets for the flour are food, chemical, and other industries, household consumption, and traders (middlemen, retailers, and exporters). Such developments in food marketing and technology have yet to arrive in Kebojong Subdistrict.

Assessing the Development of the Cassava Flour Agroindustry

Developing the cassava flour agroindustry in rural areas was expected to extend cassava marketing and agroindustrial development in rural areas, and to increase farmers' income. The project was evaluated from May to September 1992.

The price of fresh cassava during May and June 1993 in Kejobong ranged from Rp 50 to Rp 60/kg, and that of cassava flour ranged from Rp 250 to Rp 350/kg. In May and June 1992, the typical farmer produced 200 kg of cassava flour, selling it to food industries. The typical farmer group produced 500 kg of cassava flour, selling it to feed industries. The KUD, however, did not produce cassava flour, not finding it profitable.

The price of cassava roots increased from Rp 70-90/kg in August-October 1993 to Rp 95-105/kg in November 1993. Farmers and farmer groups therefore found cassava flour production unprofitable. Other farmers used cassava for feed and food. The typical farmer would use 5-10 kg/day of dried cassava to feed sheep and 40-50 kg/day for *cantir* production.

The problem

Despite the low prices (Rp 50 to Rp 60/kg) farmers said they had no problem marketing cassava roots. In contrast, producers explained they had problems marketing cassava flour because it is a new product for which food processing technology has not yet been developed, and of which few consumers know much about.

Summary

(1) Farmers, farmer groups, and KUDs had no experience in marketing cassava flour.
(2) Processors and consumers lacked information on cassava processing technology and flour use.
(3) Appropriate cassava flour processing technology must be developed if the cassava flour industry is to develop in rural areas.
(4) Further research is needed on cassava flour use.

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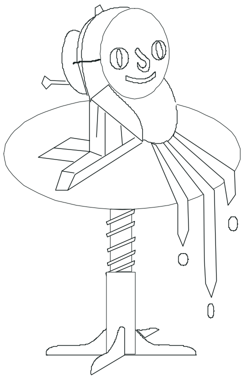

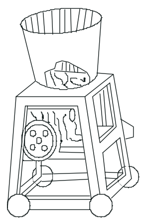

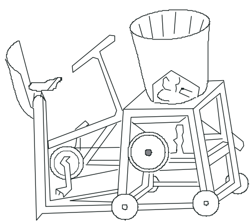

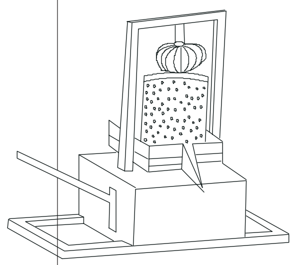

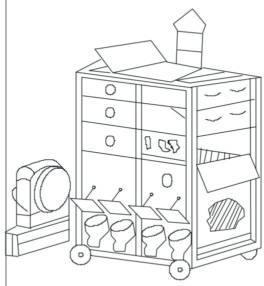

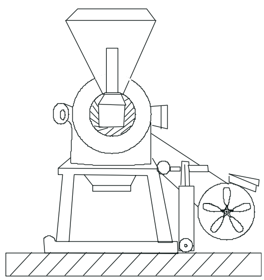

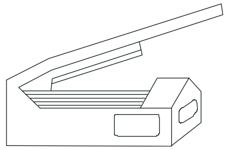

APPENDICES

Appendix I

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1. Most acronyms are explained in the "List of Acronyms and Abbreviations Used in Text," p. 402.

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Appendix II

List of Acronyms and Abbreviations Used in Text

Acronyms

AACC	American Association of Cereal Chemists, USA
ABAM	Associação Brasileira dos Produtores de Amido de Mandioca, Brazil
ABES	Associação Brasileira de Engenharia Sanitária, Brazil
ACDI	Agricultural Cooperative Development International, Colombia
AFST	Association of Food Science Technology, India
ANPPY	Asociación Nacional de Productores y Procesadores de Yuca, Colombia
AOAC	Association of Official Analytical Chemists, USA
APPYs	Asociaciones de Productores y Procesadores de Yuca, Ecuador
ASOCOSTA	Asociación de Cooperativas de la Costa, Colombia
ASTM	American Society for Testing and Materials, USA
ATAPYs	Asociaciones de Trabajadores Agrícolas y Productores de Yuca, Ecuador
BFAD	Bureau of Food and Drugs, the Philippines
BNH	Banco Nacional de Habitação, Brazil
BOI	Board of Investment, Thailand
BORIF	Bogor Research Institute for Food Crops, Indonesia
CA	Département des cultures annuelles (CIRAD)
CBN	Cassava Biotechnology Network, based in Colombia
CBS	Central Bureau of Statistics, Indonesia
CDA	Cooperative Development Authority, the Philippines
CDF	Countrywide Development Fund, the Philippines
CENDES	Centro de Desarrollo, Ecuador
CEPAGRO	Centro Estadual de Pesquisa Agronómica, Brazil
CERAT	Centro Raizes Tropicais (UNESP)
CETEC	Corporación para Estudios Interdisciplinarios y Asesorías Técnicas, Colombia

CETESB	Companhia de Tecnologia de Saneamento Ambiental, Brazil
CGPRT	Center for Research and Development of Coarse Grains, Pulses, Roots and Tuber Crops in the Humid Tropics of Asia and the Pacific, Indonesia
CIP	Centro Internacional de la Papa, based in Peru
CNPMF	Centro Nacional de Pesquisa de Mandioca e Fruticultura (EMBRAPA)
CONAB	Companhia Nacional de Abastecimento, Brazil
COOPEMUBA	Cooperativa de Productores de Mandioca de Ubajara, Brazil
COOPROALGA	Cooperativa de Productores de los Algarrobos, Colombia
COPROMA	Cooperativa de Productores de Mandioca de Acarau, Brazil
CORAF	Conférence des responsables de recherche agronomique en Afrique de l'Ouest et du Centre
CPC	Corn Products Company, USA
CRIFC	Central Research Institute for Food Crops, Indonesia
CRVZ	Centre de recherche vétérinaire et zootechnique (DGRST)
CTCRI	Central Tuber Crops Research Institute, India
CVC	Corporación Autónoma Regional del Valle del Cauca, Colombia
DANE	Departamento Administrativo Nacional de Estadística, Colombia
DEMSA	Derivados del Maiz, S. A. (private company), Peru
DEPD	Department of Economic Planning and Development, Malawi
DGRST	Direction générale de la recherche scientifique et technique, Congo
DOLE	Department of Labor and Employment, the Philippines
DRI	Fondo de Desarrollo Rural Integrado, Colombia
DTI	Department of Trade and Industry, the Philippines
EEC	European Economic Community, now the EU
EMATER	Empresa de Assistência Técnica e Extensão Rural, Brazil
EMATER-CE	Empresa de Pesquisa, Assistência Técnica e Extensão Rural do Ceará, Brazil
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária, Brazil
ENSAM	Ecole nationale supérieure agronomique de Montpellier, France
ENSBANA	Ecole nationale supérieure de biologie appliquée à la nutrition et l'alimentation, France
ENSIA	Ecole nationale supérieure des industries agricoles et alimentaires, France
EPACE	Empresa de Pesquisa Agropecuária do Ceará, Brazil
EPN	Escuela Politécnica Nacional, Ecuador
ERS	Economic Research Service (USDA)

ESAL	Escola Superior de Agronômia de Lavras, Brazil
ESALQ	Escola Superior de Agricultura "Luiz de Queiroz", Brazil
EU	European Union, often known as the EC or EEC
FAC	Facultad de Ciencias (UCV)
FACE	Fundación Adelanto Comunitario, Ecuador
FAO	Food and Agriculture Organization of the United Nations, Italy
FCA	Faculdade de Ciências Agronômicas (UNESP)
FIBGE	Fundação Instituto Brasileiro de Geografia e Estatística, Brazil (also IBGE)
FODERUMA	Fondo para el Desarrollo Rural del Ministerio de Agricultura, Ecuador
FUNDAGRO	Fundación para el Desarrollo Agropecuario, Ecuador
FUNDAIN	Fundación Paraguaya de Apoyo a la Agroindustria, Paraguay
FUNDIAGRO	Fundación para la Investigación y el Desarrollo de Tecnologías Apropiadas al Agro, Colombia
GATT	General Agreement on Tariffs and Trade, EU
GBSA	Laboratoire de microbiologie et biochimie industrielles of the Université Montpellier II, France
GNCTDC	Guangxi Nanning Cassava Technical Development Center, China (also NCTDC)
IAC	Instituto Agronômico de Campinas, Brazil
IADS	International Agricultural Development Service, New York, USA
IAEA	International Atomic Energy Agency, Italy
IAPAR	Instituto Agronômico do Paraná, Brazil
IARCs	International Agricultural Research Centers of the Consultative Group on International Agricultural Research (CGIAR), USA
IBGE	see FIBGE
IBPGR	International Board for Plant Genetic Resources, now IPGRI
IBRD	International Bank for Reconstruction and Development (also known as the World Bank), USA
IBSRAM	International Board of Soil Resources and Management, Thailand
ICA	Instituto Colombiano Agropecuario
ICH	International Child Health Unit, Sweden
ICMSF	International Commission on Microbiological Specifications for Foods, UK
ICONTEC	Instituto Colombiano de Normas Técnicas
ICTA	Instituto de Ciencia y Tecnología Agrícolas, Guatemala
IDRC	International Development Research Centre, Canada
IFRPD	Institute of Food Research and Product Development of Kasetsart University, Thailand

IFS	International Foundation for Science, Sweden
IIAP	Instituto de Investigaciones de la Amazonía Peruana
IICA	Instituto Interamericano de Cooperación para la Agricultura, Costa Rica
IIED	International Institute for Environment and Development, UK
IITA	International Institute of Tropical Agriculture, Nigeria
INA-PG	Institut national agronomique, Paris-Grignon
INCIENSA	Instituto Costarricense de Investigación y Enseñanza en Nutrición y Salud, Costa Rica
INDELMA C.A.	Industrias del Maíz C.A., Venezuela
INIA	Instituto Nacional de Investigación Agraria, Peru
INIAP	Instituto Nacional de Investigaciones Agropecuarias, Ecuador
INN	Instituto Nacional de Nutrición, Venezuela
INRA	Institut national de recherche agronomique, France
IPESAT	Institut provencial d'enseighement superieur agronomique et technique du Hainaut, Belgium
IPGRI	International Plant Genetic Resources Institute, Italy
ISNAR	International Service for National Agricultural Research, the Netherlands
ISU	Isabela State University, the Philippines
ITCF	Institut technique des céréales et des fourrages of the Céréaliers du France
KUD	Koperasi Unit Desa (Village Unit Cooperative), Indonesia
MAE	Ministère des Affaires Etrangères, France
MAG	Ministerio de Agricultura, Ecuador
MARA	Ministério da Agricultura e Reforma Agrária, Brazil
MARCA	Mabagon Root Crop Association, the Philippines
MIPRE	Ministerio de la Presidencia, Peru
MOAC	Ministry of Agriculture and Cooperatives, Thailand
MOI	Ministry of Industry, Thailand
NAPHIRE	National Postharvest Institute for Research and Extension, the Philippines
NCTDC	see GNCTDC
NRI	Natural Resources Institute, UK
ORSTOM	Institut français de recherche scientifique pour le développement en coopération, France
PCARRD	Philippine Council for Agriculture and Resources Research and Development
PMO	Prime Minister's Office, Tanzania
PRCRTC	Philippine Root Crop Research and Training Center
PRODAR	Programa Cooperativo de Desarrollo Agroindustrial Rural, Costa Rica

PRONAA	Programa Nacional de Alimentación, Peru
PROPAL S.A.	Productora de Papeles S.A., Colombia
SEARCA	Southeast Asian Regional Center for Graduate Study and Research in Agriculture, the Philippines
SECTI	Secretaría Ejecutiva de Cooperación Internacional (MIPRE)
SEDECOM	Servicio de Desarrollo y Consultoría para el Sector Cooperativo y de Micro-Empresas, Colombia
SFCDP	Secondary Food Crops Development Project, Indonesia
SIARC	Section industries agricoles et alimentaires des régions chaudes (ENSIA)
SUDENE	Superintendência do Desenvolvimento do Nordeste, Brazil
TAPPI	Technical Association of the Pulp and Paper Industry, New York
TDRI	Thailand Development Research Institute
TDRI	Tropical Development and Research Institute, UK
TPPIA	Thai Pulp and Paper Industries Association
TTFITA	Thai Tapioca Flour Industries Trade Association
TTTA	Thai Tapioca Trade Association
UAM	Universidad Autónoma Metropolitana, Mexico
UAPPY	Unión de Asociaciones de Productores y Procesadores de Yuca, Ecuador
UATAPPY	Unión de Asociaciones de Trabajadores Agrícolas, Productores y Procesadores de Yuca, Ecuador
UBA	Universidad de Buenos Aires, Argentina
UCV	Universidad Central de Venezuela
UEM	Universidade Estadual de Maringá, Brazil
UEPG	Universidade Estadual de Ponta Grossa, Brazil
UFPR	Universidade Federal do Paraná, Brazil
UFSC	Universidade Federal de Santa Catarina, Brazil
UNALM	Universidad Nacional Agraria “La Molina”, Peru
UNESCO	United Nations Education, Scientific, and Cultural Organization, France
UNESP	Universidade Estadual Paulista, Brazil
UNIVALLE	Universidad del Valle, Colombia
USAID	United States Agency for International Development, USA
USDA	United States Department of Agriculture
UST	University of Science and Technology, Ghana
UTC	Université de Tecnologie de Compiègne, France
UWI	University of the West Indies, Trindad and Tobago
ViSCA	Visayas State College of Agriculture, the Philippines

WAG	Water Activity Group of the European Cooperation in the Field of Science and Technical Research (investigates water content of substances)
WHO	World Health Organization
WIPS	“Women in Postproduction Systems,” collaborative project in the Philippines

Abbreviations

ALAB	Amylolytic lactic acid bacteria
APC	Aerobic plate count
ATP	Adenosine triphosphate
a_w	Water activities (in determining food isotherms)
BA	Brabender amylograph
BE	Starch-branching enzyme (gene responsible for the cross linkages that form amylopectin)
BMP	Bread-making potential
BOD	Biochemical oxygen demand
BU	Brabender viscosity units (for starches)
CAP	Common Agricultural Policy of the EU
CCF	Chlorinated cake flour
cDNA	Complementary DNA
CF	Control fermentation
cfu	Colony-forming unit
CG	Cyanogenic glucosides
c.i.f. (C.I.F.)	Cost, insurance, and freight
CNP	Total cyanogenic potential
COD	Chemical oxygen demand
COO^-	Chemical symbol of double-bound carbon
d.b.	Dry basis
DEAE	Diethylaminoethyl (used in enzyme analysis)
DM	Dry matter
DNA	Deoxyribonucleic acid
DSC	Differential scanning calorimetry
D.W.	Devon-Watson estimate (statistics)
ECU	European currency unit
EU	Enzyme units
f.o.b. (F.O.B.)	Free on board
FRR	Financial rate of return
fwb	Fresh weight basis
g	Gravitation constant (in centrifuging)
G.A.B.	The Guggenheim-Anderson-De Boer model used for describing food isotherms in equations
GBSS	Granule-bound starch synthase (gene responsible for amylose synthesis)
GDP	Gross domestic product
g.f.b.	Glucose-fermenting bacteria
GNP	Gross national product
GPI-ID	Indice geral de preços-demanda interna (deflator, in economics = general price index-internal demand)
hab	Habitant

HCN	Hydrogen cyanide, and sometimes used to express cyanide content in cassava
HDPE	High-density polyethylene (used for packaging)
HFCS	High fructose corn syrup, also known as isoglucose
HFS	High fructose syrup
HPLC	High-performance liquid chromatography
ICRDPs	Integrated cassava research and development projects
IQR	Interquartile range (statistics)
kDa	Kilo Dalton (measure of molecular weight)
l.a.b.	Lactic acid bacteria
l.f.b.	Lactate-fermenting bacteria
M	Molecular weight
MDF	medium density fiber board (timber)
MG	Minais Gerais, state of Brazil
MPN	Most probable number (a method of enumerating microorganisms)
MRS	de Man-Rogosa-Sharpe agar medium
MS	Modified starches
MSG	Monosodium glutamate
MTBE	Methyl tertiary butyl ether
NaCl	Common salt or sodium chloride
NGC	Nonglucosidic cyanogens
NGFI	Nongrain feed ingredients (relating to CAP)
NGOs	Nongovernmental organizations
OD	Optical density
OVL	Organic volume load
p	Pressure (used in physicochemical measurements)
PCA	Plate count analysis (for estimating microbial populations)
PCR	Polymerase chain reaction
PDA	Potato dextrose agar medium
PE	Pectinesterase (pectin pectylhydrolase E.C. 3.1.1.11)
PG	Polygalacturonase (poly (1,4-α-D-galacturonide) glycanohydrolase, E.C. 3.2.1.15)
PGL	Polygalacturonate lyase
pK_a	Negative logarithm of equilibrium constant for association (used for measuring acidification)
PNPG	*p*-nitrophenol-β-D-glucopyranoside (a chromogen)
pO_2	Partial oxygen pressure
PVC	Polyvinyl chloride
R&D	Research and development
RAPD	Random amplified polymorphic DNA
RFLPs	DNA restriction fragment length polymorphisms
RMS	% Relative root mean square error
rpm	Revolutions per minute
RVA	Rapid Visco Analyzer (equipment for measuring starch viscosity profiles, which are expressed in “RVA units”)

SDS	Sodium dodecyl sulfate
SDS-PAGE	SDS-polyacrylamide gel electrophoresis
SF	Sterile fermentation
TC	Total cyanogen content
TR	Taxa de reajuste (after readjustment, in economics)
UMS	Unmodified or native starches
UV	Ultraviolet (radiation)
V	Volt
VFA	Volatile fatty acids
VSS	Volatile suspended solids
VUC	Village union cooperative, Indonesia
w/v	Weight by volume
w.b.	Wet basis
w/w	Weight-to-weight ratio
WSI	Water solubility index

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