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A LITERATURE REVIEW AND RESEARCH RECOMMENDATIONS ON CASSAVA 'MANIHOT ESCULENTA CRANTZ'

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In the fall of 1969, a team of scientists from the University of Georgia was commissioned by the Technical Assistance Bureau of the Agency for International Development to (1) compile on a systematic basis the available information about cassava and related research now in progress; (2) synthesize, appraise, and analyze the information gathered and to determine as near as possible the broad limitations and potential of cassava as a food and feed crop; and (3) to prepare a list of research needs in their order of importance, for the orientation of futnre research on cassava.

This team, consisting of ten men, represented the areas of Agronomy, Animal Nutrition, Botany, Economics, Food Science, Genetics, Horticulture, Human Nutrition and Plant Pathology. Each of their reports appear as a separate chapter in this manuscript and in each case represents their own view on cassava intthèir particular area of specialty.

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A LITERATURE REVIEW AND RESEARCH RECOMMENDATIONS ON CASSAVA (*Manihot esculenta* Crantz)

AID Contract No. csd/2497

by

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March 1972

PREFACE

The President's Science Advisory Committee Panel on the World Food Supply recommended that the agricultural potential of vast areas of uncultivated lands, particularly in Latin America and Africa, be thoroughly evaluated and research projects initiated to develop soil and crop management practices and systems for sustained food production in these areas. However, in order to make the most rapid increases in world food supply, particularly in developing countries, it seems logical that the emphasis should be placed first on selecting a crop or crops which have the greatest potential of satisfying the huge demand for food and feed, and second, to analyze the key problems which limit the production and expansion in utilization of the crop or crops selected.

Cassava (*Manihot esculenta* Crantz) fits the first criterion well since the tubers of the cassava plant have been used extensively as a basic food crop by a majority of the people residing in regions generally between 30^{0} N and S of the equator. The root has been one of the cheapest sources of carbohydrates available to people. In some areas it has been used also as an inexpensive source of livestock feed. Its culture appears to be simple since it is readily propagated and widely adapted to a variety of soil types and climatic conditions.

Cassava has been described as a "door-yard" crop. It is found mainly on small plots and utilized for individual family needs. In some countries, however, such as Brazil and Thailand, large commercial acreages are found. Where cassava is produced commercially, the products of the plant are utilized in local industry and also are exported to

foreign markets, primarily in the form of dried chips or flour where it is utilized as a grain substitute in animal and human diets.

Inasmuch as the crop is used principally in a garden type production for home consumption, information concerning its total production, yield per hectare, insect and disease problems and economic importance is not as fully known and documented as the more extensively grown crops or those giving greater economic returns per hectare. Moreover, statistics are maintained by dry weight in some areas of the world and by fresh weight in others which complicates the comparisons needed in any type of study. However, the trends in production which are reported by the Food and Agriculture Organization in their Production Yearbook give some crude indication of the growing importance of the crop on a world-wide basis. In Latin America, average annual production apparently increased during the period from 1952/56 to 1966 from 17,374 million metric tons to 29,860 million metric tons. In Bolivia output increased by 178 percent during this period; in Brazil by 74 percent; in Colombia by 86 percent; in Panama by 136 percent; and in Peru by 119 percent. In the Far East cassava production grew during this comparable period from 12,105 million metric tons to 18,246 million metric tons; in Africa from 26,554 million metric tons to 29,372 million metric tons. However, these figures may not be completely reliable since they may represent more accurate reporting as well as genuine increases.

Diets consisting mainly of cassava are considered by most experts as deficient because of the low protein content of the tubers. However, the crop could become a more important source of food for humans and feed for animals if an efficient method were found to add proteins

artificially or by genetic manipulation and if the production and economic problems encountered could be solved. It now seems quite possible that new varieties can be developed that have higher yielding capacity and contain larger amounts of available protein than 2 percent. Additional uses for the crop as a human food should be feasible if research in this area were initiated and completed. Such considerations are particularly relevant in view of the dual problem of malnutrition and population growth in the tropical areas.

Also, there may be additional industrial uses for the crop. The root is high in starch content, which is easily extracted. Cassava starch may be substituted for other starches in making beer, paper, bags and textiles.

In spite of the above considerations, cassava has been largely overlooked by crop scientists. In view of the second criterion, a great deal of speculation has been made concerning its potential in overcoming world hunger or malnutrition, but relatively little is known about its specific limitations. Scattered throughout the world are pieces of research data, but until recently no concentrated attempt has been made to compile, synthesize and analyze this information--an effort which is clearly required to orient future meaningful research.

In the fall of 1969, a team of scientists from the University of Georgia was commissioned by the Technical Assistance Bureau of the Agency for International Development to (1) compile on a systematic basis the available information about cassava and related research now in progress; (2) synthesize, appraise, and analyze the information gathered and to determine as near as possible the broad limitations and

potential of cassava as a food and feed crop; and (3) to prepare a list of research needs in their order of importance, for the orientation of future research on cassava. The University of Georgia engaged Dr. D. J. Rogers of the University of Colorado to work with the team based on his knowledge and experience with this crop.

This team, consisting of ten men, represented the areas of Agronomy, Animal Nutrition, Botany, Economics, Food Science, Genetics, Horticulture, Human Nutrition and Plant Pathology. Each of their reports appear as a separate chapter in this manuscript and in each case represents their own view on cassava in their particular area of specialty. Dr. C. H. Hondershott, Chairman, Division of Horticulture, University of Georgia, served as chairman of the group, and Dr. F. C. Obioha, Associate Professor, Animal Nutrition, Agricultural Research Station, Umudike-Umuahia, Nigeria, served as co-chairman.

Two essential characteristics necessary in a survey of this kind were brought together in this team. First, it is an interdisciplinary group representing a broad background of knowledge and experience. Second, by far the majority were unfamiliar with cassava and could look at the published information without any preconceived ideas or bias as to its importance and potential.

Early in the investigation, it became quite apparent that the accumulation and assimilation of the information existing on cassava was a monumental task and could not be done completely on a world-wide basis within the time limit, funds and the time each team member could devote to the project in relation to his other duties. However, the

job was undertaken with enthusiasm and it is believed that the information presented represents an unbiased basic evaluation of the crop.

C. H. Hendershott, Chairman
March 1972

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CHAPTER I

Cassava (*Manihot esculenta* Crantz), the Plant, World Production and Its Importance in World Food Supply[1]

The tropical root crop cassava[2] is the seventh largest producer of staple food in the world (295). It is grown all over the tropical region and consumed as primary, secondary or supplementary staple. Products from cassava roots such as industrial starch (including derivatives) and livestock feed are used in substanial and increasing quantities in areas within and outside the tropical belt.

Cassava originated in the new world tropics (643). It was probably first domesticated in the low land areas of meso-America (present day southern Mexico, Guatemala, and Honduras) and from here the crop was probably carried throughout the American tropics by Indians long before the advent of white man (645). Earliest Mayan and Aztec chronicles mention "yuca." Cassava seeds and leaf remains were discovered in the caves in northeastern Mexico, referable to the "Laguna" culture about 2100 years old (468). The crop must have been domesticated much earlier because Sauer (660) reports the discovery of 4000-year-old Peruvian pottery depicting cassava roots.

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[1]Prepared by D. J. Rogers and S. G. Appan, Taximetric Laboratory, University of Colorado, Boulder, Colorado.

[2]The crop is called by various common names in different parts of the world. All apply to the one species *Manihot esculenta* Crantz. The names most frequently encountered are: cassava in English-speaking tropical areas, yuca in Spanish-speaking areas, mandioca or macacheira in Brazil, manioc among French-speaking peoples, and by other less well-known epithets in Indo-Malaysia. Tapioca, one of the products manufactured from the roots, is sometimes used as a common name. In this manuscript, cassava, the most common name for the crop, will be used throughout.

After Columbus, the crop was disseminated to other tropical areas of the world. The durability of cassava bread as a shipboard food was taken advantage of by the sea voyagers between the new world and the old world (728). The Portuguese probably brought it to their stations around the mouth of the Congo River during the last half of the 16th century, and it was probably introduced to countries bordering the Indian Ocean (India, Ceylon, Malaya, Indonesia, etc.) during the 18th century (409).

THE PLANT

Manihot esculenta Crantz is the only edible cultivated species in the genus Manihot comprising about 125 species. The genus belongs to the spurge family Euphorbiaceae to which several other economically important species such as para rubber (Hevea brasiliensis), castor bean (Ricinus communis), etc., belong. The computer-aided delimitation of the species of Manihot (654) revealed that several species names are synonyms of M. esculenta. These include M. utilissima, M. aipi, M. dulcis, M. flexuosa, M. flabellifolia, M. diffusa, M. melanobasis, M. digitiformis and M. sprucei. It is classified in section Esculenta of the genus.

Botany of the Plant:

Manihot esculenta Crantz is a shrubby perennial species. The plant is cultivated primarily for its tuberous roots, but young shoots and leaves are also edible and are used as food in some parts of the tropics. The plant is 1-4 meters tall. (For detailed species description see reference 650.) Stem either unbranched, tall, and

slender, or variously branched with a whole range of intermediate branching patterns to that of a highly branched plant no more than 1 meter tall. The stems are predominantly brown but sometimes yellow or silver; woody, usually with a very large pith and therefore quite brittle. The nodes along the stem are usually prominently raised. Leaves are simple, palmately lobed, with 3-10 linear, obovate, or pandurate lobes. Inflorescence is a panicle, generally 2-10 cm long. The flowers are monoecious, the pistillate basal, opening first, the staminate apical, opening later. Fruit is a schizocarp, usually winged, 3 carpellate, 3 locular. Seeds are carunculate, mottled or plain. Under cultivation the plant is propagated vegetatively by means of stem cuttings, and adventitious roots radiate from the base of the stem cuttings. Within the first few months of the plant's growth some of the roots become tuberous with reserves of carbohydrates. The tuberous roots are variously shaped - from long and slender to globose; each 0.25-1.00 m long (sometimes longer), 5-15 cm in diameter and weighing usually 1-5 kilos. There is great variability in the yield of roots per plant; a total of 2-3 kilos of roots per plant is common but improved strains yield more than 10 kilos of roots per plant.

Several aspects of the botany of cassava are discussed by Rogers (641, 643, 645, 647), Appan (63), and Rogers and Appan (654, 655). Capinpin and Bruce (147) described the floral biology of cassava. De Toledo (764) discussed the anatomy and ontogeny of cassava flower. Anatomy of the vegetative parts is described by Viegas (783). Holleman and Aten (371) briefly describe the anatomy of the tuberous roots. Photoperiodic effects on the development of tuberous roots are

reported by Nair and Sinha (531) and Bolhuis (121). A light period of 12 to 16 hours was considered optimal for promoting tuber formation. Menon et al. (498) observed that application of plant growth regulators significantly influenced the length and weight of storage roots in cassava. Longman (460) investigated the effect of orientation and root position on apical dominance in cassava.

WORLD PRODUCTION

World cassava production has steadily increased from 62.5 million metric tons in 1955 to 85.6 million in 1968 (295). The quantity produced in each of the various cassava growing countries is presented in Table 1-1. Total production is probably greater than reported because cassava is still grown largely by subsistence farmers who cultivate small, irregular and scattered plots, usually with much intercropping and undershifting cultivation (204). Therefore, the collection and interpretation of actual production statistics is difficult. In fact, accurate statistics from the areas where cassava is predominant are almost nonexistent. This may be due to the fact that it is frequently treated as a "door-yard" crop and does not enter into the usual report pattern required for agricultural statistics. A distribution map of cultivation would not be meaningful, inasmuch as some cassava is produced in nearly all tropical areas of the world, but the frequency of cultivation can not be accurately judged.

According to FAO statistics (295) total world production in 1968 amounted to 85.6 million metric tons and occupied 9.8 million hectares of land. However, these figures do not include the large production

TABLE 1-1. World Production of Cassava in 1968.

	AREA IN HA (X 1,000)	METRIC TONS (X 1,000)	YIELD 100 KG/HA
N. & C. America (15 nations)	92	547	60
Cuba	30	200	67
Dominic Rep.	15	155	103
Haiti	25	80	32
South America (11 nations)	2,409	33,179	138
Argentina	25	273	110
Bolivia	10	160	160
Brazil	1,998	29,203	146
Colômbia	152	900	59
Ecuador	39	280	71
Paraguay	100	1,504	150
Peru	42	500	119
Venezuela	41	341	84
Asia (16 nations)	2,410	20,911	87
Ceylon	73	425	58
China (Taiwan)	21	342	161
India	335	4,520	135
Indonesia	1,600	11,800	74
Malaysia, W.	17	280	165
Philippines	83	496	60
Thailand	135	2,000	148
Viet-Nam, Nth.	100	700	70
Viet-Nam, Rep.	35	260	74
Africa (40 nations)	4,872	30,869	63
Angola	120	1,545	129
Burundi	75	875	117
Cameroon	114	762	67
Central Africa Rep.	200	1,000	50
Congo, Brazz.	100	400	40
Congo, Rep.	750	8,100	108
Dahomey	180	1,142	63
Gabon	52	130	25
Ghana	172	1,446	84
Guinea	30	420	140
Ivory Coast	200	530	27
Kenya	90	620	67
Liberia	65	430	66
Madagascar	280	910	33
Malawi	5	110	220
Mali	13	220	159
Niger	20	150	75
Nigeria	1,200	6,700	56
Rwanda	15	190	127
Senegal	63	232	37
Sudan	17	132	78
Tanzania	270	1,125	42
Togo	150	1,120	75
Uganda	530	2,000	38
Zambia	42	160	38
Oceania (5 nations)	11	119	108
World (88 nations)	9,794	85,625	87

Source: FAO Production Yearbook, 1969 (295)

area on mainland China. The Continent of South America produced slightly more than the African Continent and Brazil alone produced about one-third of total world supply (Table 1-1).

IMPORTANCE OF CASSAVA IN WORLD FOOD SUPPLY

There is no doubt that cassava makes a significant contribution to the world food supply. Coursey and Haynes (204) have stated that cassava may be regarded as the staple food of about 200 million people in the tropics.

Cassava contributes to the world food supply in the following ways: 1) roots are detoxicated and consumed as primary, secondary or supplementary food; 2) roots are used as livestock feed, and the livestock products are consumed by man, and 3) cassava starch or flour is incorporated by food industries into food products for human consumption.

The most important use of the cassava root, approximately 95% of the world production, is the consumption of fresh roots as a primary, secondary or supplementary food. Its importance as a staple food in the various countries can be assessed by determining the per capita intake, but such estimates are available only for certain countries. Brazil is an example of a country consuming cassava as a primary staple. Brazilian consumption was reported to be 124 kg of roots per person per year compared to 39 kilos of rice, 27 kg of beans and 17 kg of corn (figures for the year 1962-63). In urban areas the per capita intake was 42 kg, whereas in rural areas it was 200 kg (546).

Jones (409) presents the results of several dietary surveys conducted in many areas of Africa. In the Belgian Congo 50-79% of the total calories consumed was contributed by cassava (244). Another

survey in the Congo region indicated 27-72% (212). In southern Nigeria, 24.9-55.7% of the diet was composed of cassava (540). It contributed 38-47% of the calories in the diet in a survey in Ghana (331). In east Africa cassava contributed 12-20% of all calories in one survey in Ruanda-Urundi (454). These figures indicate that in Africa cassava varies from being the primary staple in certain areas, to being the secondary or supplementary staple in certain other areas.

In Indonesia dietary surveys conducted by Bailey (78) indicate that cassava is the primary staple in Java and Madura region. As much as 1,010 calories out of an average daily intake of 1,592 calories, are contributed by cassava. In the Indian State of Kerala, cassava, along with fish, forms the main item of the diet of the working classes (200), but no reports of dietary surveys are available.

Cassava is being used as livestock feed for dairy cattle, beef cattle, goats, pigs, and chickens (see Chapter VII). Phenomenal increase in the quantities of cassava imported by European Economic Community is reported by UNCTAD-GATT (774). The imports have steadily increased and reached 883,514 metric tons in 1966, which is more than double the quantity imported in 1962. The Federal Republic of Germany accounted for 79% of this import. Although this represents only 1-3% of the total world production, it nevertheless signifies the increasing trend in the use of cassava as a competitive livestock feed.

Cassava starch and flour is used by several food industries for the manufacture of a variety of food preparations such as sauces, gravies, soups, baby foods, desserts, biscuits, pie and cake fillings, salad dressings, mustard powders, confectionary and as a substitute for

sago. The roots are also used for the manufacture of fermented beverages such as beer.

Several fortified products have been made, using cassava as one of the ingredients. The Central Food Technological Institute (82) in India developed Paushtik Atta and a fortified grain called Tapioca Macaroni (both the products consist mainly of tapioca flour, wheat flour and peanut flour). Kwee et al. (437) made a pasta product composed of rice, corn, soya and tapioca enriched with fish protein concentrates.

ADVANTAGES OF CASSAVA AS A STAPLE FOOD CROP

As mentioned before, world cassava production is steadily increasing despite the fact that nutritionists have blamed it for kwashiorkor and a host of other maladies, and economists predicted that economic growth would result in the replacement of cassava with other so-called "superior" staple food crops.

In any given agricultural region, certain crops are favored and grown as a part of the food production system generating man's nutritional needs. An analysis of the factors which favor the adoption of cassava in preference to other staple food crops in such systems would throw some light on the relative importance of cassava in indigenous food production systems. In this context some of the advantages of cassava are described below as follows:

High Calorie Productivity.--de Vries et al. (807) concluded that cassava's productivity in terms of calories per unit land per unit time was significantly higher than other staple food crops. Coursey and Haynes (204) indicated that cassava can produce 250 x 10^3

calories/ha/day as compared to 176 x 10^3 in case of rice, 110 x 10^3 of wheat, 200 x 10^3 of maize, and 114 x 10^3 of sorghum. They also pointed out that grain crops have been subjected to intensive improvement research so that the limits of their genetic potential for yield have almost been reached, whereas the tropical root crops are still virtually untouched and there is wide scope for substantial improvement.

Greater Biological Efficiency as Food Producers.--Coursey and Haynes (204) indicated that root crops have higher biological efficiency as food producers, and part of this efficiency stems from what might be called structural engineering considerations. In a grain crop the edible portion, the seed, has to be supported above ground and a substantial portion of the mass of the plant is devoted to structural support which has to increase roughly parallel to any increase in useful yield. In root crops the edible part of the plant is hypogeous and no support is needed. Hence, there is less limitation on the proportion of the total mass of the plant the edible portion constitutes. In wheat only up to 36% of the total dry weight of the plant is edible, whereas in root crops 63-85% is edible.

The Crop Is Not Season Bound.--In most of the tropical areas cassava can be planted anytime of the year.* This allows the farmers greater flexibility in their work schedule.

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*For maximum yield, however, it is necessary to synchronize the planting time with the rainfall distribution pattern so as to enable the plants to obtain greater amounts of moisture in the initial growing period and lesser and lesser as the crop approaches harvesting time.

The harvesting can be delayed if necessary for several weeks without serious changes in the composition and quality of roots. This wide flexibility in planting and harvesting time enables the farmers to utilize their spare time, after attending to the main crop or chief avocation, thereby avoiding the necessity to hire large numbers of laborers during the peak planting and harvesting season as in the case of many other season bound staple food crops. This is significant because mechanized cassava cultivation is as yet not practicable in most of the cassava growing regions.

Cassava as a Famine Security Crop.--Due to the fact that cassava roots can be left in the ground without harvesting for several weeks or even months, local growers usually retain cassava plants in the field as a security against famine and other unforeseen food shortages. Cassava is ideally suited to be grown as a subsistence crop and the bulk of cassava produced in the world even today is through raising cassava plants as a backyard crop. In some areas a few of the roots of a single plant will be harvested and used to meet the family's needs for that day, and the remaining roots will be left intact for future use. This admirable suitability of cassava as a subsistence crop is the primary reason why cassava is tremendously popular in areas of subsistence farming in the tropics throughout most of the world.

Low Cost of Production.--The comparatively low cost of production of cassava is evident in the fact that cassava is one of the cheapest foods in most of the cassava growing regions. This is attributed to several factors such as low labor requirement, easy cultivation, high productivity, low investments, etc.

Ecological Adaptation.--The cassava plant is well adapted to a wide range of ecological conditions. Jones (409) describes the ecological adaptations of cassava as follows . . .

"The range of cassava in open field cultivation is essentially confined to the tropics, although it has been grown commercially as far north as the southern United States and as far south as northern Argentina. Approximate boundaries for its culture may be taken to be from 30°N to 30°S. In equatorial regions it may be grown 2000 meters above sea level. It does best at temperatures that vary only moderately from 18°C, although temperatures up to 35°C are not harmful. But it cannot stand cold and growth stops at about 10°C. It is killed by frost."

Thus, cassava is valued for several outstanding ecological adaptations, among which the following 3 are perhaps the most significant: (1) its drought tolerance, (2) its ability to grow in sub-optimal soils, and (3) its aggressiveness towards weeds and insect pests.

Certain cassava varieties can grow in regions with as little as 500 mm of annual rainfall, and other varieties are adapted to regions with 5000 mm rain, provided water does not stagnate in the root zone. The plants need sufficient moisture only in the early stages to get established and thereafter it has the capability to withstand drought periods of considerable intensity during which most other food crops would perish. The reserves of carbohydrates in the roots enable the plants to make a quick start when moisture becomes available again.

On account of this flexibility of the crop with respect to its moisture needs, farmers are able to raise successful crops of cassava in regions with low annual rainfall inadequate to support the

cultivation of many of the cereals. It is considered as a safe risk crop in areas with erratic rainfall distribution and danger of drought. In some areas the total productivity of the land is maximized by raising a crop of cassava after the main cereal crop, thereby taking advantage of the scanty rain which is sufficient for cassava but insufficient for a second cereal crop. During the 1943 famine in India, due to drought, over a million persons died in Bengal (a province where cassava was not being grown) whereas there were almost no starvation deaths in the State of Kerala where cassava was being grown extensively (82). This rugged quality of cassava gives it a competitive superiority over cereals and can promote the productive use of agricultural niches presently unsuitable for cereal cultivation (66). This is particularly important since the U. S. President's Science Advisory Committee report (631) indicates that 1.78 billion hectares of potentially arable land in the world is as yet unutilized.

It is said that cassava can grow in depleted soils where even many weeds will not grow, however, as in the case of its drought tolerance, the eco-physiology of this adaptation has not been adequately investigated. Jones (409) indicates that cassava roots penetrate deeper and tap nutrients from lower soil strata which are inaccessible to many cultivated annuals. Cassava cultivars are capable of growing on soils ranging from a stiff marine clay with a pH of 8 or 9 to sands and loose laterites with a pH of 5 to 5.5 (645). Most of the wild species of Manihot exhibit weedy tendencies and are usually observed to colonize disturbed habitats (653). There is a

general tendency in many parts of the world to grow cassava in sub-optimal lands and use superior lands for other crops. Hence, the crop has been grown year after year, ever since its domestication, in depleted soils, and the farmers have been selecting cultivars better adapted to such conditions. On account of this, many of the cultivars extant today appear to have become adapted to low soil fertility conditions and do not respond optimally to higher levels of soil fertility (470).

This ability of cassava to grow in sub-optimal soils offers it a competitive superiority over other staple food crops, and perhaps this is the most significant aspect to be considered in evaluating the importance of this crop in indigenous food production systems.

Cassava defends itself well against weeds if the proper variety is chosen and adequate soil water and nutrients are available. Usually within 3 to 4 months after planting, the crop puts up a dense canopy of foliage and the weeds beneath are shaded out. Papadakis (577) reported that in Africa when a soil was infested with Imperata brasiliensis, cassava was planted densely and, thus, the grass was controlled.

As far as is known at the present time, cassava has been relatively free from serious infestations of pests and diseases, particularly in the old world where the crop was transported from its new world home, but most if not all of the associated insects and diseases appear to have been left behind. In Africa it is greatly valued for its invulnerability to the migratory African locust (Locusta migratoria migratorioides). Wood (838) has suggested that one of the cyanogenic glucosides in cassava, linamarin, which serves as a non-toxic precursor

of hydrogen cyanide, is used by the plant to repel insect pests. When the tissues of the plant are attacked, linamarase will be liberated and coming into contact with its substrate produces hydrogen cyanide (839). Abraham (4) states that in the State of Kerala in India cassava is one crop on which no insecticides or pesticides are ever used or even recommended.

CHAPTER II

Genetics and Cultivars of Cassava[1]

Our knowledge of the mode of origin and ancestry of cassava is mostly hypothetical. The species M. esculenta is not known to exist as a self-perpetuating natural population (a population flourishing as a wild species) anywhere in the world today (692). Sohmer (693) hypothesized that a species complex -- a group of closely related Manihot species -- existed, and this complex was in the process of rapid speciation and range extension when the Indians arrived on the scene. They discovered that many of the members of this group produced a more or less edible root and began cultivating some of the members of the complex; since then they have been maintained by man through vegetative propagation under cultivation (694). Based on computer-aided analysis of phenotypic variation, Rogers and Appan (655) inferred that species such as M. aesculifolia, M. rubricaulis, etc., could have been the progenitors of the domesticated genotypes. The great complexity of M. esculenta gene pool, as it exists today, indicates that it became enriched through introgressive hybridization (65). Rogers (645) pointed out that because of the biological nature, it would be possible for cassava cultivars, once introduced, to hybridize with locally occurring native species in the neotopics. The preliminary cytogenetic evidence reported by Appan et al. (66) indicates that even though varied ecological specializations are inherent in the constituent closed gene

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pools of Manihot, the predominantly functioning reproductive isolating mechanisms are possibly prezygotic and the genus appears to be an aggregate of easily interchangeable germ plasm.

Some preliminary aspects of the genetic structure of today's cassava gene pool are discussed by Appan et al. (66). The predominant outcrossing of this monoecious species has contributed to the enormous recombination of the genetic material at the intraspecific level, and the vegetative propagation of this crop facilitated the preservation of many of these numerous gene combinations. There are indications that in the process of world-wide dissemination of cassava cultivars, the primary and subsequent transplantations of subsets of cassava gene pool leading to the founding of colonies resulting from the tremendous proliferation of the subsets at their respective transplant points, apparently lead to the manifestation of "founder effect" in the cassava gene pool.

CYTOGENETICS OF THE SPECIES

Knowledge of the fundamental cytology of this crop is scanty. Perry (597, 598, 599) concluded, on the basis of cytological analysis of the members of the family Euphorbiaceae, that the basic chromosome number of the genus Manihot is 9, and that M. esculenta is a tetraploid. Magoon (471) critically studied pachytene karyotypes in conjunction with cytogenetic data and confirmed the polyploid origin of M. esculenta. Jennings (397) suggested that it is an allopolyploid.

The diploid chromosome number of hundreds of cassava cultivars has been determined by various workers (339, 470, 598, 693) in different parts of the world and there is no variation from 2n=36. The only

exceptions are the counts made by Boiteau (111, 112, 113, 114) with 2n numbers of 4, 8, 12, 16, 24 and 32. Perry (598) considered these counts very unusual and Darlington and Wylie (217) rejected these as miscounts. Several workers (1, 3, 5, 340, 341, 343, 470, 477, 479) have induced colchiploids in cassava. The chromosome counts of about 15 wild Manihot species have so far been made and all of them are reported to have 2n=36 chromosomes (211).

Perry (598) reported the somatic chromosome morphology of a few cassava cultivars (and also 2 wild species) and pointed out that they are quite uniform. Sohmer (693, 694) studied meiotic metaphase I chromosomes of several cultivars and reported that in general the chromosome size and configurations are approximately the same. Extensive karyomorphological studies are being reported by Magoon and associates, this includes morphology of the pachytene chromosomes of M. esculenta (480), cytomorphology of induced polyploids in cassava (479) and cytomorphology of interspecific hybrids between M. esculenta x M. glaziovii (475, 482).

Cassava cultivars are reported to have varying degrees of sterility. Cours (201) observed that 20% of the cultivars studied by him were male sterile. Sohmer (693) pointed out that clonal stocks have been maintained for centuries through vegetative propagation, and there has been an accumulation of spontaneous mutations through these years because the plants did not pass through sexual reproductive cycle and as such most of the mutations did not get eliminated. Moh and Valerio (505) and Hsu and Valerio (378, 379) investigated cytological abnormalities of some cassava cultivars with the aim of determining the advantageous

effects of cytological aberrations, as heterosis is often associated with heterozygosity for deletion, inversion or translocation of chromosome. They observed that the aberrations were able to be transmitted through generations of somatic division, but there was no evidence to ascertain that these aberrations were advantageous while they did not appear to be deleterious either. The major difference between M. esculenta and its related wild species, according to Rogers (645), is that M. esculenta is generally less fertile. This is natural because as in other vegetatively propagated crops farmers have been selecting cultivars without regard to fertility. Jennings (397) observed in East Africa that, due to severity of brown streak virus, farmers have frequently evolved new varieties by propagating from self-sown virus-free seedlings and this resulted in the maintenance of a relatively high seed setting ability in the native cultivars in that region. Magoon et al. (478) and Jos et al. (414) determined the mechanism of pollen abortion in some male sterile lines. Degeneration of individual microspores was reported to be due to the failure of the separation of microspores from the tetrad which lead to the formation of empty anthers, whereas in certain other male sterile lines the pollen abortion appeared to be due to the persistent nature, abnormal behavior and development of the tapetum. They reported that meiotic abnormality was not the cause of pollen degeneration in the material studied by them. Jennings (397) reported that variations in pollen fertility was not correlated with variations in ovule fertility; cultivars which were above average for pollen fertility did not necessarily have above average ovule fertility.

Little published information is available with respect to the inheritance patterns of the genetic traits in this crop. Magoon (471) indicates that biometrical indices are being prepared to rationalize breeding procedures. Doku (237) observed positive correlation between root yield and certain other characters of the plant and indicated that a knowledge of the inheritance pattern of those characters are of crucial significance in designing breeding procedures. Magoon (471) reported that studies were also underway with respect to objective assessment of genotype environment interaction of agronomic, morphological and other important characteristics of promising germ plasm collections and hybrids to evaluate their phenotypic stability and identification of genetic systems conferring wider adaptation.

In order to systematically evaluate the genetic variability existing in the genus Manihot, and to investigate the cytogenetic relationship of M. esculenta with its related wild species, computer-aided taximetric studies of the Manihot closed gene pools are being conducted by Rogers and associates (63, 66, 654). Closed gene pools represent the biologically most meaningful operational units in natural populations, and being the largest interbreeding units, they also represent the most efficient sampling units for evaluation studies. Taking advantage of the speed and efficiency of modern computers, effective methods have been developed (653) which deploy a series of interlinked computer programs, the sequential application of which aids accurate delineations of the closed gene pools in natural populations (64). The computer output presents graphic indications for the recognition of patterns of the genetic structure such as

introgression, genetic drift, adaptive radiation, incipient primary speciation, secondary speciation, zones of gene exchange consequent on the breakdown of reproductive barriers, etc. (65). The 18 closed gene pools (including the 3 newly discovered ones) which together constitute the North American segment of Manihot have been delimited (655). Their geographic domains have been delineated, and their ecological adaptations and tolerance limits have been defined. Working hypotheses have been advanced for the proposed cytogenetic investigations as outlined in the 2nd phase of the taximetric methods (63). The delimitation of the closed gene pools in the South American segment of the genus is in advanced stages of completion.

Classification of the Cultivars:

Thousands of cassava cultivars are extant under cultivation today, and all of these have originated as open pollinated seedlings (rarely as somatic mutants). Usually the crop is harvested before the sexual phase begins, but occasionally if the harvesting is delayed the plant will set seeds. Some seedlings may attract the attention of the farmers on account of their hybrid vigor and freedom from virus diseases (the virus disease, cassava mosaic, is widespread all over the world on account of easy transmission of the virus through vegetative propagation of the crop, and the seedlings being free of the virus usually stand out in a field of infected plants). Predominant outcrossing in this crop, on account of its monoecious flowers, promotes the production of innumerable new recombinant types and potentially each F_1 recombinant in cassava can become a cultivar, unlike in seed-propagated crops wherein a variety must satisfy the requirement of possessing genetically

fixed traits which do not significantly break down in the progeny. When a seedling becomes a cultivar, farmers give it a name to identify it. Sometimes a cultivar gets transported to another region and gets another name and as such it is not uncommon for one cultivar to masquerade under different names. Rogers (645) located one cultivar in Costa Rica, the name of which was "Brazil". This cultivar was carried by the Dutch from Brazil to Indonesia, returned from Indonesia to Cuba and from Cuba taken as an ideal producer to Costa Rica.

Usually only a few cultivars (about 1/2 dozen) would be popular in any given locality and the local growers would be quite familiar with the characteristics of those cultivars enabling them to identify them easily. When agricultural workers began building up assemblages of cultivars, classifications of the cultivars became necessary. Rogers and Fleming (650) review in depth the history of classification of cassava cultivars. Zehntner (844) divided the Brazilian cultivars into two groups, one group with high concentrations of the cyanogenic glucosides and the other supposedly none. Tests conducted by Rogers (645) of about 100 Jamaican cultivars proved that such a separation is not taxonomically valid. The CN^- concentrations are present in a continuum from low to high and do not appear to be correlated with any morphological or ecological feature, and in some known instances they vary with the maturity of the plant.

Several informal classifications of cultivars restricted to local areas have been developed by workers in different parts of the world. These are largely useful for the identification of the cultivars growing in these regions but cannot relate to the plants in other growing regions

of the tropics. Such are the classifications by Cours (201) for Malagasy, Koshy (427), and Abraham (2) for India, Chandraratna and Nanayakkara (164, 165) for Ceylon, Templeton (753) for Malaysia and Doku (238) for Ghana.

A universal classification of the cultivars based on natural relationships is an essential prerequisite for efficient evaluation and utilization of the genetic variability embodied in M. esculenta gene pool. The work of Rogers and Fleming (650) completed after 18 years of research attempts to respond to this need. The large number of variants of cultivated species, differing in some cases only in one biochemical property, maintained only by intercession of man's conscious cultivation, exhibit an apparent continuum in their phenotypic properties; in contrast to members of wild species which are constantly subjected to selection pressures maintaining a high frequency of genotypes manifesting phenotypic properties varying within specific limits conferring maximum fitness. However, efficient methods of analyzing the phenotypic data could enable us to discover "constellations" of cultivars reflecting natural relationships. Therefore, in order to evaluate the overall phenotypic similarity between a large number of cultivars and to discover constellations among them reflecting natural relationships, computer-aided methods were developed by Rogers and associates (275, 276, 362, 644, 646, 649, 651, 653, 834). The application of the mathematics of the information theory in assessing the relationships amongst reticulately related members, such as cassava cultivars, is illustrated by Fleming and Rogers (304).

Rogers and Fleming (650) divided the cassava cultivars into two major subdivisions, based on characters of roots and stems. The larger subdivision contains all those cultivars having roots with roughened and generally dark brown epidermis, and stems either brown, red, or yellow. The smaller subdivision (about 30% of the cultivars) is characterized by having roots with smooth epidermal layer, colored light tan, sometimes with pinkist cast. The stems are "silver" or light gray. Below these two categories, the cultivars are clustered into 19 groups, each group delimited rather tenuously based on 15 morphological characters (Table 2-1). The classification was based on population samples collected mainly by David J. Rogers and are samples of the new world tropics only. Inasmuch as the crop was derived from the new world tropics, the authors felt that this classification would be applicable for cultivars in any part of the world. This classification, purely morphological in nature, was designed largely to aid plant breeders and other persons involved in agricultural research to relate their own material to the world-wide types that exist. No attempt was made by the authors to provide Latin names to the groups because of the nature of variation in this species. This computer-aided classification of M. esculenta (650) provides a sound framework for 1) developing an universal catalog of cassava cultivars describing their economically significant phenotypic attributes; 2) efficiently designing cytogenetic investigations to understand the karyological mechanisms of differentiation in this group of cultivars, and 3) building computer banks of phenotypic and cytogenetic information so as to enable breeders to search and pick appropriate genetic stocks by manipulating the bank.

TABLE 2-1. Phenotypic Characters Employed in the Computer-Aided Classification of Cassava Cultivars.

ROOT CHARACTERS

1. Texture of root surface
2. External color of root
3. Color of root cortex

STEM CHARACTERS

4. Color of stem
5. Storey length
6. Nature of scars on stem
7. Branching of plant

LEAF CHARACTERS

8. Number of lobes of leaf
9. Leaf lobe shape
10. Sinuosity of lobes of linear leaves
11. Sinuosity of lobes of obovate leaves
12. Length of median lobe
13. Width of median lobe
14. Petiole color
15. Color of young foliage

Source: D. J. Rogers and . . S. Fleming (650)

STERILITY AND BREEDING BEHAVIOR

Many cassava varieties are male sterile as reported by Capinpin and Bruce (147). Sterility and poor fruit set of cassava have been studied by Moh (504) and Jennings (397). The partial sterility of cassava may be an obstacle in making certain combinations and Martin (491) has suggested the use of mass selection techniques to overcome this problem. It may also be a valuable tool for quickly developing gene pools or used in population breeding as is currently being done with sorghum. This would be especially important for improved protein and improved starch development. This factor coupled with an asexually propagated plant might be an extremely important key factor. The specific cause of partial sterility in some cassava species is not known, but Jennings (397) is of the belief that it may be a genic or chromosomal unbalance caused by the outcrossing of cassava to related species. Magoon et al. (476) investigated the mechanism of pollen abortion in twelve male sterile lines of cassava and they noted ten lines with a failure of disjunction of individual microspores from the tetrads at the proper time; however, sterility in two of these lines resulted from the persistent nature, abnormal behavior and development of tapetum. Magoon et al. (476) also reported that meiotic abnormality was not the cause of male sterility in the twelve lines investigated. Pollen sterility in the induced tetraploids of cassava ranged from 65% to 78% and seed fertility was also poor under open pollinated conditions (477). A triploid showed 79% pollen sterility and the triploid plants did not set seed on selfing; however, slight seed fertility was noticed under open pollinated field conditions. Abraham et al. (5) found that

tetraploids were lower in vigor, productivity and hardiness, higher in water content, and less capable of resisting unfavorable conditions when compared to diploids.

CULTIVARS AND VARIABILITY ASSOCIATED WITH GENETIC DIFFERENCES

Yield variability associated with genetic differences is difficult to ascertain except under uniform controlled trials since they would be confounded with environmental effects. However, the results of Abraham's (3) investigations suggest a fairly high heritability of yield and he has reported producing some hybrids with superior yield and vigor. He demonstrated the usefulness of inbreeding cassava to increase predictable results in a breeding and improvement program. Doku (237) studied the breeding of cassava for yield and noted a significant association between certain plant characteristics and root yield.

Chandraratna and Nanayakkara (166) studied the reproductive process of cassava as it related to production of hybrids. They reported that the stigma remains receptive up to twenty-four hours, dried pollen remains viable for six days, insect and wind both carry pollen, eight to nineteen hours are required for fertilization to occur, flower drop in about ten days, and seeds require 2 1/2 to 3 months to mature. Jennings (394), while working in East Africa, reported that Manihot melanobasis contributed factors which enhanced the fertility of its hybrids with cassava and five local varieties which included the local variety, Katoto.

Increases in production may result from the improvement of production methods and cassava varieties. The evaluation of present cultivars for local adaptability and to changing production practices

will be of great importance in future expansion of this crop. In established cassava varieties, bud sports have been reported (499); however, the low frequency of these mutations would offer few opportunities for their utilization to develop better types. Mechanized production and harvest of cassava appears to have a good potential. Cassava is customarily propagated by cuttings; however, the high fertility level of Manihot melanobasis offers a source of genes for good capacity to set seeds. True seeds might be used to propagate this crop if desirable types could be developed by mass selection, hybridization and inbreeding. Furthermore, this might be utilized as a means of obtaining virus-free stock if it can be demonstrated that viruses are not seed transmitted.

PROSPECTS FOR IMPROVING YIELD

The Brazilian average yield of cassava roots in the last few years has been about 14 metric tons/ha, compared to 8.4 metric tons/ha on a world-wide basis (546). However, Normanha (546) states that for the State of Sao Paulo, Brazil, on a basis of 135,000 ha (1968-69), yield has been estimated to average 17.5 tons/ha which is 20% greater than the Brazilian and 52% higher than the world's average yield. This is also greater than the average yield of cassava in India which was reported to be about 12.5 tons/ha (471).

Increased production per unit area appears possible for cassava even without extensive breeding programs if locally adapted cultivars with high yielding potential are grown under controlled and improved production systems. Nevertheless, the great variability and species crossability of cassava appear to offer many opportunities in a

breeding program to develop new and more productive types for commercial production.

In trials (Table 2-2) of cassava cultivars carried out in the Paraiba River Valley on a tertiary soil, a new cultivar, Mantiqueira, created by the Instituto Agronomico was superior to all others (663). This cultivar was reported by Schmidt and Pereira (663) to have precocious initial shoots, high productivity, roots of excellent type and to be easy to harvest. It was also reported to have upright plants which makes cultivation easy, an apparent resistance to the root rotting and bacteriosis caused by Xanthomonas manihotis (Arthand-Berthet) Stars, tolerance to drought, and to be free of virus induced mosaic.

Ramos (616) stated that a collection of 200 Manihot clones were being evaluated for yield earliness, protein or nitrogen content, and resistance to diseases on the very fertile, heavy soil of the Cauca Valley in Palmira. The best varieties for yield were Llanera, Yuca-Papa, Tempranita, Amarilla, Respetada, and the clones CMC 29, 39, 40, and 93, and the Brazilian variety, Santa Catarina. Ramos (616) states, "the Llanera variety has been outstanding for yield in the Cauca Valley, producing up to 78 metric tons of roots/ha in experimental plots and 40 tons/ha in grower fields. The CMC 29 and 39 varieties have been better adapted to warmer temperatures of the Caribbean Coast." The earliest maturing varieties were Llanera, Yuca-Papa, and Tempranita, being ready for harvest in about 10 months (616).

PROSPECTS FOR IMPROVING FOOD AND FEED VALUE

One of the most important aspects of cassava breeding in addition to total yield is the prospects of improving the protein and starch

TABLE 2-2. Average Production of Roots in Tons Per Hectare from 5 Experiments Harvested on Two Vegetative Cycles for the Years 1962 to 1966.

Treatment	Experiment 1	2	3	4	5	Mean	Percent production of check variety
Mantiqueira	47.9	45.6	49.2	49.2	44.8	47.3	189.2
IAC-7-127	35.1	37.2	34.2	38.6	33.5	37.2	148.8
IAC-5-165	34.2	31.4	36.5	32.5	29.6	32.8	131.2
Branca de Santa Catarina (check)	24.6	25.9	22.3	25.7	26.5	25.0	100.0
Marion	19.8	16.9	15.8	19.1	16.3	17.6	70.4
d.m.s. (Tukey 5%)						3.8	

Source: N. C. Schmidt and A. S. Pereira (663)

content. Bolhuis (118) recorded the protein contents in fresh roots of seedlings and their clones from the cross Manihot saxicola with the clone Basiorao. In his study, the protein content in fresh roots range from 0.46 to 2.06%, and Bolhuis reported that there was poor correspondence between the protein content of seedlings and the clones derived from them. Bolhuis stated, "the hybrids from cross of Manihot utilissima with Manihot saxicola seem to offer the greatest possibilities, although they are adversely affected by a high degree of poisonousness and unfavorable habitus."

Ramos (616) reported in initial tests the highest content of total nitrogen on dry basis for roots was 6.40% in the variety Llanera; he also stated twelve varieties had more than 7% protein in the leaves.

PROSPECTS OF DISEASE AND NEMATODE RESISTANCE THROUGH BREEDING

Studies of mosaic resistance in cassava by Doughty (242) suggest that this trait is multigenic and hybrids obtained by him had a high level of resistance but none with complete immunity. First generation hybrids were all tree-like when M. glaziovii was used as one parent. In the M. esculenta x M. glaziovii hybrid, some cytological abnormalities have been observed; however, a gene flow from one species to another appears to be a potential breeding method for cassava. Nichols (536) studied virus resistance in crosses of tree-type Manihot with shrub-type cassava. Graner (342) reported that in cassava a narrow lobe leaf was dominant to wide lobe leaf and dark skin roots were dominant to light skin roots.

Guiran (350) evaluated 42 cassava clones for resistance to Pratylenchus brachyurus (nematode); he reported Touye clone to be one of the

most susceptible and B25x50 crosses one of the most resistant. Tables 2-3 and 2-4 present plant and root characteristics for several cassava cultivars (549).

RECOMMENDATIONS FOR BREEDING IMPROVED CULTIVARS

A breeding program for cassava should include short-term and long-term goals. This crop is usually propagated vegetatively by stem cuttings which should be an advantage on a short-term basis for selecting high-yielding, locally adapted clones for commercial production. Short-term goals should be devoted to the collection and evaluation of existing cultivars for adaptability to areas of production, yielding ability, disease and insect resistance, and types suitable for mechanical production and harvest. Attributes of importance for types to be mechanically harvested are single stem plants, short internodes, and bulbous roots clustered close to point of attachment near the soil surface.

Success for an increase of protein in cassava roots appears possible as indicated by the 6.40% protein content of the variety Llanera. Bolhuis (118) suggested the protein content of cassava varieties might be increased by use of high protein varieties from Indo-China and crosses of M. utilissima with M. saxicola in breeding programs.

Short-term goals might include objectives for cassava improvement suggested by Magoon (471) and others, as follows:

1. High-yielding varieties possessing excellent response to fertilization (80 to 100 tons/ha).
2. Resistance to "cassava mosaic", scale insects, red mite, and drought.

TABLE 2-3. Recommended Cassava Varieties According to Use or Principal Pest Problem of the Region.

Principal problem	Recommended varieties	Purpose of crop
Excess sprouting.... (virus)	Preta Itu	General industrial use
Bacterioses.....	Branca Santa Catarina Cafelha IAC-12-1 IAC-5-165 Brava de Itu Itu	
Stem borers.....	Brava de Itu Itu IAC-12-1	
Bacterioses.....	Guaxupé Santa Piraqununga Ouro do Vale	Human consumption (table)
Stem borers.....	Santa Piraqununga	
Excess sprouting.... (virus)	Itu	Forage (raw roots)
Bacterioses.....	Guaxupé Santa Piraqununga	
Borers.....	Santa Piraqununga Itu	

Source: E. S. Normanha and A. S. Pereira (549)

TABLE 2-4. Some Characteristics of the Main Cassava Varieties for Industry, Table or Forage for the State of Sao Paulo, Brazil.

Varieties	Resistance to attacks caused by			Resistance to plagues		Root characteristics			
	Bacteria (*Xanthomonas manihots*)	Fungi (*Cercospora henningsii*)	Virus Branching	Borers (*Coelosternus*, spp.)	Larvae in bud	Skin	Cortex Outside	Cortex Inside	Pulp or core
						Color/texture	Color	Color	Color
Industrial Varieties									
IAC-12-1	Good	-	-	Good	Good	Clear, smooth	White	White	White
Branca Santa Catarina	Good	-	Average	Average	Average	Clear, smooth	White	White	White
Preta	Average	-	Optimum	Good	Average	Brown, rough	White	White	White
Cafelha	Good	Average	Poor	Average	Average	Clear, smooth	Light pink	White	White
Brava de Itu	Average	Average	Average	Good	Good	Brown, rough	White	White	White
Itu	Good	Average	Average	Very good	Good	Brown, rough	White	White	White
Branca do Vale	Poor	-	-	Very poor	-	Clear, smooth	White	White	White
Marion	Average	Poor	-	Very poor	Good	Clear, smooth	White	White	White
Table and Forage Varieties									
Vassourinha	Poor	Average	Poor	Very poor	Very poor	Brown, rough	White	White	White
Santa	Good	Good	-	Very poor	Good	Brown, rough	Purple	White	White
Guaxupé	Good	Very poor	Poor	Very poor	Poor	Brown, rough	White	White	White
Tatu	Average	-	Poor	Very poor	Poor	Brown, rough	White	White	White
Piraqununga	Good	-	-	Very good	Good	Brown, rough	Light cream	Light cream	Cream
Ouro do Vale	Good	-	-	Good	Good	Brown, rough	Cream	Cream	Cream

Source: Normanha and Pereira (549)

3. Tuber quality -- high starch (30 to 35% in fresh tubers) and high protein (6 to 8%) content, low HCN.
4. Early maturity (10 months).
5. Close-set buds on the stems.
6. Varieties with unbranched stems (late flowering).
7. Roots clustered close to the point of attachment and near soil surface.
8. Bulbous roots that are easily removed from the soil.
9. Good keeping quality.

Many long-term goals are outlined by Martin (491) in the introduction and genetics research program below:

1. Introduction Program

(a) Collect and maintain all possible species of *Manihot*.

(b) Study the interrelations of the species by morphological, cytological, and biochemical approaches.

(c) Screen the collection of traits of agronomic value, including disease resistance, morphology of roots and shoots, tuberization of roots, resistance to rain, drought, insects, and burrowing animals, and for starch characteristics and amino acid profile.

(d) Screen for crossability to *Manihot esculenta*.

(e) Screen for intercrossability of selected species.

(f) Establish a virus-free site for assembling and maintaining a cassava varietal collection.

(g) Assemble a collection of virus-free varieties.

(h) Document the characteristics of these varieties.

(i) Select contrasting characteristics for conventional genetic studies.

2. Genetic Program

(a) Develop a genetic program to test the mode of inheritance of particularly useful single-gene characteristics.

(b) Test the heritability of yield, plant size and shape, and other agronomic characteristics.

(c) Test the effects of inbreeding and outcrossing on yield.

(d) Determine pollen vectors and degree of outcrossing.

(e) Develop and characterize a series of inbreds.

(f) Use single genes to improve existing inbreds.

(g) Develop open-pollinated populations with a wide genetic base, utilizing male sterile techniques.

(h) Use mass selection techniques to gradually modify such populations.

(i) Screen all generations for potentially valuable individuals.

(j) Cross cassava to species with desired traits.

(k) Introgress new and desirable traits into inbreds and open-pollinated populations.

(l) Introduce varietal selections into agronomic field trials.

The formation of a Cassava Cooperators Group to develop plans for a cooperative uniform replicated yield trial to be conducted at several locations should expedite the evaluation of existing cassava varieties. Group regional testing and evaluating of varieties provides information on the performance of varieties under a wide range of environmental conditions.

Long-term breeding goals for cassava should include studies to determine the inheritance patterns of characteristics for existing varieties and wild types. Investigations to determine genetic information should include combining ability, inbreeding, linkage, and mass selection. A study of the reproductive mechanisms in cassava should provide information to assist in the development of breeding procedures for controlled hybridization of this crop.

CHAPTER III

Cultivation and Fertilization of Cassava[1]

The great prominence of growing cassava results mainly from the capacity for producing large amounts of food calories in the form of carbohydrates per unit land with a relatively easy culture and low labor requirements, compared to other food plants. With minimal effort and very poor conditions the yields may be as low as 7,500 kg/ha (3 tons/acre) while under better conditions the yields may even amount to 50,000 kg/ha (20 tons/acre) (70, 426). This may rank cassava first in production capacity compared to Irish potatoes, sweet potatoes, yams, taro, etc. (453, 624), and it also surpasses definitely the yield of any cereal crop. In this respect, estimates indicate that the yield is 2 to 4 times that of rice and maize in West Africa (412) and about 10 times that of wheat (289).

CLIMATIC CONDITIONS

The cultivation of cassava has always been limited to the tropics. Its success is considered to be dependent on a warm not too humid climate, and recently evidence was submitted that cassava can adapt itself also to a subtropical or warm temperate climate. According to Averre (75) and Tracy (765) cassava has been grown since 1900 in the Southern United States, especially in Dade County, Florida, although unpublished reports (personal communications, Dr. D. J. Rogers) stated that it had been grown by the Seminole Indians long before this date.

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[1]Prepared by K. H. Tan and A. R. Bertrand, Department of Agronomy, University of Georgia, Athens, Georgia.

The areas in which cassava is extensively grown have the following climatic types. In Latin America it is mostly cultivated in areas with Koppen's[1] Am and Aw climatic types and to a less extent also in Af and Bs or Bwh climates (813, 817). In Brazil the area includes the Amazon basin, while in Colômbia cassava is generally restricted to the northern part of the country. In Africa cassava growing areas are located according to De Viliers (797) from Senegal in the west, over Nigeria and the Congo, to the northern tip of Malagasy (Madagascar) in the east. These areas vary in climate types from "equatorial humid" to "tropical summer wet" (815), corresponding approximately to Am and Aw (or savannah) climatic types of Koppen. In tropical Asia the areas with cassava have a somewhat wider variation in climate. In India this climate would be an Aw or As monsoon climate, while in Southeast Asia, comprising of south Burma, Ceylon, Thailand, Cambodia, Laos, South Viet-Nam, Malaysia, Brunai, Serawak, the Philippines and Indonesia, the climate is designated as a humid-tropical climate with 8 to 12 months with mean monthly temperatures >18°C (Koppen: A) and a mean relative humidity of at least 65% (308). In Indonesia cassava is scattered throughout the country from the warm humid climates in the lowlands (Koppen: Af) to the cool dryer climates of the mountains (Koppen: C), with the largest concentration of cassava again in Ama and Asa climates.

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[1]Koppen's classification of climate (743): A=coldest month >18°C; B=steppe climate; C=average annual temp. between 18 and -3°C; a=warmest month >22°C; h=annually >18°C; i=difference between coldest and warmest month <5°C; f=humid; s=summer dry; w=winter dry; m=condition between f and w (or s).

It can be summarized that the areas for cassava production are generally limited between 12°N and 12°S latitude, if changes in climatic conditions with elevation are not taken into consideration. In general the climate in the tropics changes with altitude above sea level. Rainfall increases and probably reaches a maximum at about 1500 to 2000 m above sea level. Temperature decreases with increasing altitude. Differences in temperature in Indonesia (743) can be calculated with the formula:

$$t = 26.3 - h \times 0.6^{\circ}C$$

where 26.3 is the temperature at sea level and h is the elevation in hectometers. So at high elevations temperatures comparable to those of temperate climates can be reached. As cassava is a tropical plant, it requires moderate temperatures and a frost-free growing period, although it is produced in Southern Brazil where frost may occasionally occur. For this reason it usually does not grow well at higher altitudes, where temperatures may drop below the optimum limits for cassava plant growth. At 800 meters above sea level the cassava plant starts to require a longer growth period for a good harvest of roots. The yield also decreases considerably (426). Above 1500 m conditions become very unfavorable for growth.

With respect to rainfall De Viliers (797) considered an average annual rainfall of 760-1,015 mm (30-40 in) optimum for cassava growth. However, the present authors have observed that depending upon other conditions cassava can also be grown successfully in high rainfall areas, i.e., in Indonesia cassava is grown and produces well in areas

with 4000 mm rain annually. The same is true for parts of Latin America and India (162, 436, 813). If the rainfall is too high the young cuttings may be damaged by fungus, while the chances for root-rot in mature stands increase. On the other hand, if the rainfall is too low, like in a steppe climate, the roots may develop into woody and stringy knobs, although the cassava plant is known to resist lengthy drought periods. An arid climate or an abnormal dry spell in moderately humid regions will affect cassava growth unfavorably. In older stands the plants will be defoliated by an extreme drought period and consequently the roots will not develop sufficiently. There are, however, some varieties and species well adapted to drought but the roots are usually small. The plants may also become more susceptible to pests and diseases under drought conditions.

SOILS

General Requirements:

Cassava may grow in a wide variety of soil conditions, but for optimal growth and good harvest it requires a friable and rich soil. The best result may be obtained on light textured soils, provided sufficient amounts of plant nutrients are available. Generally, in heavy textured soils the roots do not enlarge sufficiently, while in less fertile soils unsatisfactory results are obtained due to a poor development of the foliage. Here again varietal differences can be noted in various parts of the world. A point worth mentioning in this respect is the fact that Oxisols (lateritic soils) in the tropics are characterized by a very high clay content (up to 90% in the subsoil)

and yet they do not exhibit the plasticity and stickiness as would be expected by such a fine texture. This is due to the presence of a very stable aggregation by free iron.

The cassava plant also can not endure marshy, swampy or hydromorphic conditions and, in regions dominated by paddy rice, cassava is usually cultivated as an "upland" crop.

Since cassava has high nutrient requirements, it tends to deplete the soil, especially with respect to soil potassium content (234). This will be discussed more in detail in the section on mineral nutrition. Because in most countries cassava does not produce significant financial returns, the best soils tend to be reserved for more profitable crops and only the poor soils are planted with cassava. In this way, it is usually argued, even the poorest soil may then produce some food. This fact is probably one of the reasons why the reported yields in many countries, especially Africa, have been so low.

Soils of Cassava Areas:

In the following discussion of soils and soil characteristics, the reader should keep in mind that only soils considered as potentially important for cassava cultivation are reported. The soil groups were selected from the viewpoint of their potential for growing cassava, by superimposing the corresponding maps for soil types and climatic conditions over that of the cassava growing areas of the world, specifically in Latin America, Africa and Asia. Adaptation of these soils for cassava production is quite possible under proper water and fertility management.

Latin America.--Depending upon the conditions the following soil groups may be found in the cassava growing regions of Latin America (132); red yellow latosols; red yellow podzolic soils; non-calcic and calcic brown soils; red and brown mediterranean soils; terra roxa soils; tropical mountain ando soils; desert soils; and alluvial soils. A comparison of these soil types with the U. S. Comprehensive System of Soil Classification is presented in Table 3-1.

Oxisols and Ultisols are widely distributed in Brazil, Peru, Equador, Colômbia, Bolivia, Paraguay, and Costa Rica. Brazil is covered generally by Oxisols and Ultisols with Alfisols occurring in the northern and southern part. In the northern part of Colômbia, where cassava is mainly concentrated, the soils are Oxisols, Ultisols and Entisols.

Not all of these soils discussed above are presently suitable for cassava cultivation but could become important under proper management. Most cassava is produced on Oxisols, Ultisols and Entisols. The Aridisols are too dry but if irrigation were available they probably could be adapted. The Andepts are suitable soils in areas where the cool climate is not a limiting factor. The latter is worth investigation, since in Indonesia the lowland Andepts (743) provide excellent soil conditions for cassava, tobacco and other horticultural crops. The Alfisols, with mineral fertility and structure being generally good, may also be important for cassava, especially the Terra roxa. According to Bramao (132) two types of Terra roxa soils should be recognized in Brazil and Paraguay: e.g., Terra roxa "ligitima" and Terra roxa "parana." Both originated from diabase rocks of the

TABLE 3-1. Summary of the soils in the cassava growing regions, as correlated with the U. S. Comprehensive System.

U. S. Comprehensive System	Latin America	Africa	Asia
Entisols	Alluvial soils	-	Alluvial soils
Inceptisols	Trop. Mount. Ando	-	Andosols
Aridisols	Desert soils	Desert soils	-
Vertisols	Trop. Dark Clay soils	Trop. Dark Clay soils	Grumusols
Mollisols	-	Brown Trop. soils of humid regions	Acid Brown Forest soils
Alfisols	Non-calcic Brown	Trop. Ferruginous	Red and Brown Mediterranean
	Calcic Brown		Non-calcic Brown
	Red and Brown Mediterranean soils		
	Terra roxa		
Ultisols	Red Yellow Podz.	Trop. Ferruginous	Red Yellow Podz.
Oxisols	Red Yellow Latosols	Ferralitic soils	Red-Reddish Brown Latosols
		Ferrisols	

Brazalian Trapp formation and are considered the most productive soils of South America. Terra roxa of Parana is well adapted for growing coffee, sugar, pineapple, upland rice, cotton, maize and groundnut. Bramao (132) reported further that the production of coffee may decline after a few years of cultivation, due to a rapid decrease of organic matter content and deterioration of the moisture retention capacity of the Terra roxa soil. If this occurs, the productivity of this soil could be restored by proper management and irrigation and would be well adapted for cassava.

Africa.--Using the ORSTROM and INEAC soil classification system (230, 231), the soils in the cassava growing regions of tropical Africa may be distinguished roughly into the following groups: tropical ferruginous soils (or fersiallitic soils); ferralitic soils; ferrisols; tropical dark clay soils; brown tropical soils of humid regions; and desert soils.

Using the Comprehensive System (Table 3-1), it appears that the Oxisols, Ultisols, and to some extent the Alfisols, are the most widely distributed soils in the cassava growing areas of Senegal, Guinea, Liberia, Ivory Coast, Nigeria, Congo, Ruanda, Tanzania and the northern tip of Mozambique. Most of the Aridisols are located to the north bordering the Sahara. Dark clay soils of the tropics are scattered throughout the countries with the largest distribution found in Nigeria and the Congo (255).

As stated before, the Aridisols are unsuitable for cassava production, unless irrigation can be provided. Since no data are available in this respect, this problem may have some potential value

for research on cassava cultivation in arid climates. The Vertisols will create problems, due to their poor physical properties but could be utilized under proper management programs. The most important soil groups for cassava production in Africa are the Alfisols, Ultisols and Oxisols. However, the best soils among these groups are usually selected for cocoa and yams, but generally crops such as coconut, rubber, oil palm and cassava can be found on all these soils. Finally, it should be noted that to some extent the brown tropical soils of the humid regions originating from volcanic ash can be considered to belong to the best soils of Africa. From the description as reported by D'Hoore (230), it is, however, difficult to conclude whether this soil has properties similar to those of the Andepts.

Asia.--The soils occurring in the cassava growing areas of Asia are as follows: Alluvial soils; red, red-yellow, and reddish brown latosols; red-yellow podzolic soils; red and brown mediterranean soils; non-calcic brown soils; grumusols; acid brown forest soils; andosols; and paddy soils (256, 733, 742, 744).

According to the Comprehensive System (695, 696), the most widely distributed soils in Southeast Asia are probably the Oxisols and Ultisols. Extensive areas of Entisols are usually confined to the Irriwady and Sittang Valleys of Burma, the central plain of Thailand, the Mekong Delta of Cambodia and South Viet-Nam, the Red River Delta of North Viet-Nam, the east coast of Sumatra, the west, south and east coast of Borneo and the north coast of Java. The Alfisols occur mostly in the dryer regions, i.e., in central Burma, Ceylon, in the central plain and in parts of northeast Thailand, in East Java and the Lesser

Sunda Islands of Indonesia. Vertisols are scattered throughout Southeast Asia usually in relatively small areas of East Java, Madura, the Lesser Sunda Islands of Indonesia, the Philippines, South Viet-Nam, Cambodia and the central plain of Thailand. Large areas of Vertisols can only be found in India. The occurrence of Mollisols are limited to the cooler regions of the uplands and mountains, while Andosols are confined to the volcanic areas of Sumatra, Java, Bali and the southern part of Luzon. Paddy soils may occur in the rice producing areas of Southeast Asia on any of the soil groups mentioned above.

The Entisols, Oxisols and Ultisols are perhaps the most important agricultural soils. Entisols, with the exception of "cat clays," saline and mangrove soils, are extensively used for rice and other tropical crops, e.g., maize, cotton, tobacco, coconut, jute, kenaf, etc. Oxisols and Ultisols are cultivated mostly with peanuts, sweet potatoes, cassava and fruit crops such as bananas, pineapples, citrus, papaya, watermelons, jackfruits, etc. The most important rubber, cocoa, sisal and oil palm plantations are located on these soils. In Java, specifically, these soils support population densities of approximately 1,930 persons per square kilometer. Alfisols are moderately fertile soils and respond well to fertilization, providing sufficient amounts of water can be supplied. With adequate irrigation, satisfactory yields can be obtained for cotton, tobacco, soybean and kapok. The same is valid to a certain extent for the Vertisols. Andepts, on the other hand, are very fertile soils. In the lowland of north Sumatra the famous Deli tobacco wrappers plantations are located on ando's, while in the mountains of Java the best tea plantations and extensive

horticultural operations are found on Andepts. The more rugged part of the mountains covered by Andepts are planted with Pinus merkusii Jungh and De Vr., an indigenous pine species of north Sumatra (745).

Fertility Status:

The major land use and general agricultural potentialities of the soils occupying the cassava regions of the world have been discussed above. This is considered essential as background information for developing long-range programs of land utilization. In the following pages more detailed considerations on the chemical and physical characteristics of the soils are given. Results of investigations on cassava soils are adequate to establish a high correlation between yield and chemical composition or between yield and physical condition of the soil. However, great differences may occur not only in the chemical composition, but also in the physical properties of the soils used for cassava production. Table 3-2 demonstrates the limits within which the chemical composition of the soils may vary in several cassava growing regions of Southeast Asia (326). The data were, in fact, collected for "rice soils", but since cassava in Southeast Asia is frequently grown on the same soils as a second major crop, they may also serve as general information for cassava cultivation, however, they should not be viewed completely as desirable for cassava. The point is that this is the general condition though it may not be optimum. It can be noticed from the data that the soils are relatively well supplied with nitrogen, but they are low in available P and K. The Ca and Mg content are moderately high, considering the humid tropical conditions in which the soils have been formed.

TABLE 3-2. Average percentage chemical composition of "rice soils" in selected countries of Southeast Asia.

Country	N	Citrate soluble		Exchangeable	
		P	K	Ca	Mg
Southern India	0.070	0.007	0.015	0.979	0.481
Ceylon	0.184	0.005	0.128	0.200	0.211
Burma	0.112	0.005	0.013	0.420	0.676
Malaysia	0.132	0.002	0.006	0.189	0.263
Thailand	0.248	0.003	0.011	0.189	0.168
Philippines	0.179	0.006	0.013	0.325	0.173
Average	0.154	0.005	0.031	0.384	0.329

Source: Glander, 1957 (326)

The composition of many good Oxisols is within the limits shown in Table 3-2, that of Ultisols is usually lower, whereas that of Alfisols is higher in Ca and Mg, but may often be lower in N, P and sometimes K. The same is true for the Vertisols. The chemical composition of Andepts shows, in general, higher nutrient contents than those of Table 3-2, especially the nitrogen content which may amount to 1.0% in the A horizon (745). Yield trials of cassava on these soils should yield valuable information on nutrient requirement for high production.

Variations in pH, which usually reflect the base saturation of the soils, are shown in Table 3-3. It can be noticed that the conditions in Oxisols and Andepts are moderately acid, on the other hand, in Ultisols very acid, whereas in Alfisols and Vertisols they are neutral to slightly alkaline, corresponding to conditions with moderately low, very low and high percentage base saturation, respectively. A comparison of yield trials on these soils should yield valuable information on the effect of pH on cassava production.

The data in Table 3-3 also show broad differences in soil texture, which is a factor of importance for a successful root development of cassava plants. Oxisols, Alfisols and Vertisols are characterized by a finer texture than Ultisols and Andepts. In this respect it should be pointed out again that Oxisols exhibit in general a lighter textural characteristic or coarser feeling, despite the high clay content. As previously mentioned, this is due to a stable aggregation, creating a friable condition in the soil. Vertisols and Ultisols are considered to be very poor in physical condition. The fine texture in combination with the presence of expanding montmorillonoids are the cause in

TABLE 3-3. Selected physical properties of soils in Southeast Asia (average of 15 pedons for each soil group).

Soil	pH_{H_2O}	Mechanical composition			Type of clay
		sand %	silt %	clay %	
Oxisol	5.6	6.1	23.7	70.2	Kaolinite
Ultisol	4.3	30.1	28.1	41.8	Kaolinite
Alfisol	6.9	13.1	21.8	65.1	Halloysite
Vertisol	7.2	4.4	28.9	66.7	Montmorillonite
Inceptisol (Andept)	5.1	21.7	58.5	19.8	Allophane

Source: K. H. Tan (742)

Vertisols, while the acidic condition and very low base saturation are responsible for the poor physical condition in Ultisols. Alfisols are intermediate between Oxisols and Vertisols, while Andepts can be considered to have the best physical properties among the soils concerned. Comparisons of experimental results on these soils should give some insight into the effect of the soil physical structure on the size, shape and quality of cassava roots.

CULTURAL PRACTICES

Plant Material:

Many varieties of cassava are available for plant propagation. For edible purposes strains with the highest starch and protein content but little or no HCN content are preferable. Time to maturation of the roots is also a factor in the selection of a proper variety. Early cassava is considered to mature within 6 months, whereas late cassava can be harvested in the tropical lowlands no earlier than 7 months, and many varieties require more than 10 months. For the production of starch or tapioca flour and "gari", late varieties with high starch content are selected as planting material. The roots of these plants are usually high in HCN content and consequently bitter in taste and unsuitable for direct consumption.

For the propagation of cassava, stem cuttings are used. Seeds have been employed only for breeding purposes. A large number of cassava varieties have been known not to flower in the lowlands of Indonesia. The best cutting material is obtained from 1-1.5-year-old cassava stands. Cuttings should be made from mature parts of the well

developed stem, e.g., 1.5 meters up, measured from the rootneck. The green top part of the stem is considered inferior as planting material and the lower the section on the stem the better will be the material for cuttings, as illustrated by the data in Table 3-4. Although it has occasionally been found in Africa (816) that planting long cuttings (45 cm = 18") would result in higher tuber yields than planting short (15 cm = 6") cuttings, it has been the experience of the present authors that 20-25 cm (8-10") cuttings will do sufficiently as planting material. The use of shorter cuttings permits a higher rate of multiplication (746) with a given amount of plant material. However, short cuttings may be more difficult to establish should conditions, such as low soil moisture, be unfavorable. Short cuttings would dry out more quickly.

The cuttings should be planted as soon as possible, but can be stored, if needed, in a dark, cool place for as long as 10 days. Longer storage than this increases the risk of the cuttings drying out. In some areas, the cutting material is stacked together or shocked and covered with a wet cloth. This maintains a high relative humidity around the plant material and prevents rapid drying out. This greatly increases storage life. Old cuttings when planted in the field may be severely affected by termites. Pre-treatment of the cuttings with insecticides and growth promoting substances will no doubt aid in solving these problems, especially when short cuttings are involved. However, data are unavailable in the literature and the need for more detailed research in this respect is apparent.

TABLE 3-4. Average germination percentage, root- and starch-yield as affected by cutting material.

Stem part	Germination %	Root yield tons/ha	Starch yield tons/ha
Top	41.4	13.2	1.54
Middle	77.8	19.0	2.13
Base	82.7	19.7	2.11

Source: A. S. Huertas (380) and C. D. Molinyawe (507)

Land Preparation:

Land preparation is usually started in the dry season, except in regions with a very humid climate. Here land is prepared at the end of the "heavy rain" season and cuttings are then planted in the beginning of the "dry" season, during which they can take advantage of the lighter rainfall for early root development. In lower rainfall areas earlier plowing is sometimes necessary during the time when some rainfall is still present, due to the fact that the soil is too dry and hard for tillage during the dry period.

For large plantings, the land is usually prepared as for corn. The field is plowed to a depth of at least 25 cm, followed by disk harrowing. Planting can then be done in rows on the flat surface. However, on heavy soils in humid areas banking, or making beds on ridges of at least 15 cm height, should be practiced in order to permit drainage and decrease root rot associated with high soil moisture levels. In some cases a second plowing is needed before the harrowing. Many farmers in Southeast Asia plow to a depth of only 15 cm, but this results frequently in a decrease in tuber yield.

Methods of Planting:

Cassava is cultivated either as a major crop or as an intercrop with upland rice, peanut, corn, rubber, etc. Intercropping with upland rice gives a poor effect on tuber yields, due to the shallow land preparation conducted for rice cultivation and the unfavorable effect of shading under the shadow of the faster growing rice plants. With peanuts, cassava is usually planted a month after planting the peanuts, since planting at the same time would result in the cassava overshadowing the

peanut plants during the growth stage. With corn, planting at the same time is feasible. Between young rubber plantings, cassava is sometimes grown as an annual cash crop.

The cuttings are planted either horizontally, slightly inclined or perpendicular to the soil surface. Upside down placement should be avoided. Perpendicular planting is considered the best method, but this requires much more hand labor. Likewise, depth of planting must be regulated in terms of environmental conditions. Too much exposure of the cuttings in areas where soil moisture is below optimum could result in poor stands and low yields. Horizontal placement and thus complete coverage of cuttings may affect yields unfavorably, particularly in the drier regions and in light or heavy soils. However, in the case of mechanization of the culture, this may be the most practical method of planting.

Planting is usually in rows or in a square (equidistant) pattern. Row planting is generally used when intercropping with corn or rubber. In the case of intercropping with corn, cassava is planted in rows at 1.50 m between each row or with two rows of corn between each cassava row. The spacing will depend on such factors as soil fertility, the growth characteristics of the variety, rainfall, etc. On good soils and with adequate soil moisture, a close planting distance can be used, e.g., 80 x 80 cm, with which a population of 15,600 plants per hectare can be obtained. However, planting too close is considered to increase the chances for lodging, particularly with some varieties (426). On the other hand, a greater planting distance is required on poor and/or droughty soils, such as 1 x 1 m, which gives 10,000 plants per hectare.

Under some conditions a wider spacing is employed.

As soon as the cuttings have sprouted new stems, many growers choose to maintain one stem on the plant, while the remainder is removed completely. Others prefer the development of two stems per plant. This is of special importance for periodic harvest of young cassava leaves for human and livestock consumption. However, the choice between growing a "one-stem" or a "double-stem" plant is still open for investigation, since it has been based mostly on personal experience or preference rather than on scientific research.

Finally, it should also be mentioned, that in Indonesia considerable success has been obtained by grafting superior cassava clones on to cassava root stocks. In some cases, yields have been doubled or even tripled. This particular practice is known to the author to exist only in Indonesia and is not a widespread practice. However, it is worthy of mentioning as a method of increasing yield though in many cases it would probably be economically non-feasible.

Maintenance Operation:

This consists chiefly of replacement of cuttings that did not develop, weeding and additional plowing. Cuttings, which fail to develop, must be replaced as soon as possible, if a uniform stand and higher yields are to be obtained.

Weeding is usually required for a month or two after planting, and, where necessary, the soil should be cultivated again, especially where heavy rains have closed or compacted it. In relatively wet areas special attention should be given to maintaining proper drainage to

prevent flooding conditions. In many cases a second weeding may be necessary after about two months of growth. A cassava stand with the proper variety, planting distance and soil fertility has, after three months, usually grown so closely together, that further weed development is not necessary or minimal. Probably only the border areas of the plantation are at this stage still infested by weeds, which are sometimes controlled by planting hedges of legumes, e.g., Tephrosia candida. Weeds may become serious again at the time the plants start to mature and the stand becomes thinner in foliage by shedding off the old leaves. Chemical weed control is no doubt of importance, but not much data are available in this respect (416). Research is needed to determine the precise kind, amount and time of application of herbicides for the specific cassava producing areas in question.

Harvest and Storage:

Harvest is conducted when the plants are mature, which depends upon many factors, e.g., variety, soil, planting distance, climatic conditions, etc. Usually only the roots are harvested, but occasionally the leaves are utilized for human and livestock consumption. Whole plants have been utilized in some areas as silage. Recently, it has been reported that cassava stalks have been harvested for the production of particle board (303). The cassava plant is considered mature when the roots have attained a maximum content in starch. The distinction in age made in this respect between "early" and "late" varieties is generally 8 months. Early varieties are mature within 6-8 months, whereas late cassava requires 12-18 months to reach maturity. The exact time is

dependent upon rainfall and temperature. In the cooler climate of the mountains, cassava sometimes requires 24 months before it can be harvested. In general, it can be stated that the total root weight and carbohydrate content increase until the age of approximately 14 months and both decrease again approaching the period of 21 months (426).

At the age of 9 to 12 months, root yields may vary from 1.5-6 kg per plant, corresponding roughly with 18,000-50,000 kg per ha. Grown with the proper management on good soils, late varieties may yield as much as 70,000 kg roots per ha (426) or more. When peeled the net yield may decrease by 20%; although with many varieties the loss by peeling is only about 10%.

Harvest is usually done by hand, however, mechanical harvest is under investigation (158, 160). Mechanical harvest is usually less thorough than hand harvest as more roots remain in the soil. In order to facilitate mechanized harvest, the plants may be cut completely to stumps prior to harvest and the stems can be collected and used for cuttings for the next crop.

After harvest cassava cannot be stored in a fresh condition as can Irish potatoes. Within 1 week or less if bruised, the roots turn greyish in color, or develop many bluish veins (75). Storage procedures reported with partial success are: slicing the roots and drying in the sun; burying the roots in a cool place; refrigerating the roots at -2.5^{o}C; and desiccating the roots to 10-12% moisture (75). A new practice of waxing the roots has been tried but the results are not definite. For direct

consumption the farmer seldom harvests his crop at one time but lets the plants grow further. This cannot be done indefinitely since the starch content decreases, while the roots become woody and develop many cavities as the plants grow older. Fresh cassava is preferred in the many preparations for local consumption, but where conservative preparation is required, the peeled roots, after careful washing, are steamed or cooked, followed by cutting into very thin chips and dried in the sun for 4-5 days. Kept in a dry place these chips may be stored for a period of at least 1 year and are favored snack after frying in deep fat.

For industrial purposes, the entire harvest is dried without prior cooking, to a moisture content of 12-14% (325). The roots are frequently peeled in the field to reduce 20% of the transport expenses and are then washed with clean water. To conserve these roots, chips are made from the raw, fresh material, which are dried in the sun or in the oven with controlled heat and air flow. The latter is faster; sundrying requires 4-6 days before the product is ready for market. The quality of raw cassava chips, as is the case with cooked cassava chips, is considered to increase (426) as the chips are made thinner, however, reports have been published (325) that for consumption purposes the thickness of raw cassava chips should not be less than 1.8 cm (3/4") because of rehydration problems. The yield of dried chips from 100 kg fresh roots is approximately 40 kg. This product, called "gaplek" in Indonesia, is suitable for human and livestock consumption as well as for the production of tapioca flour, pearl and flake.

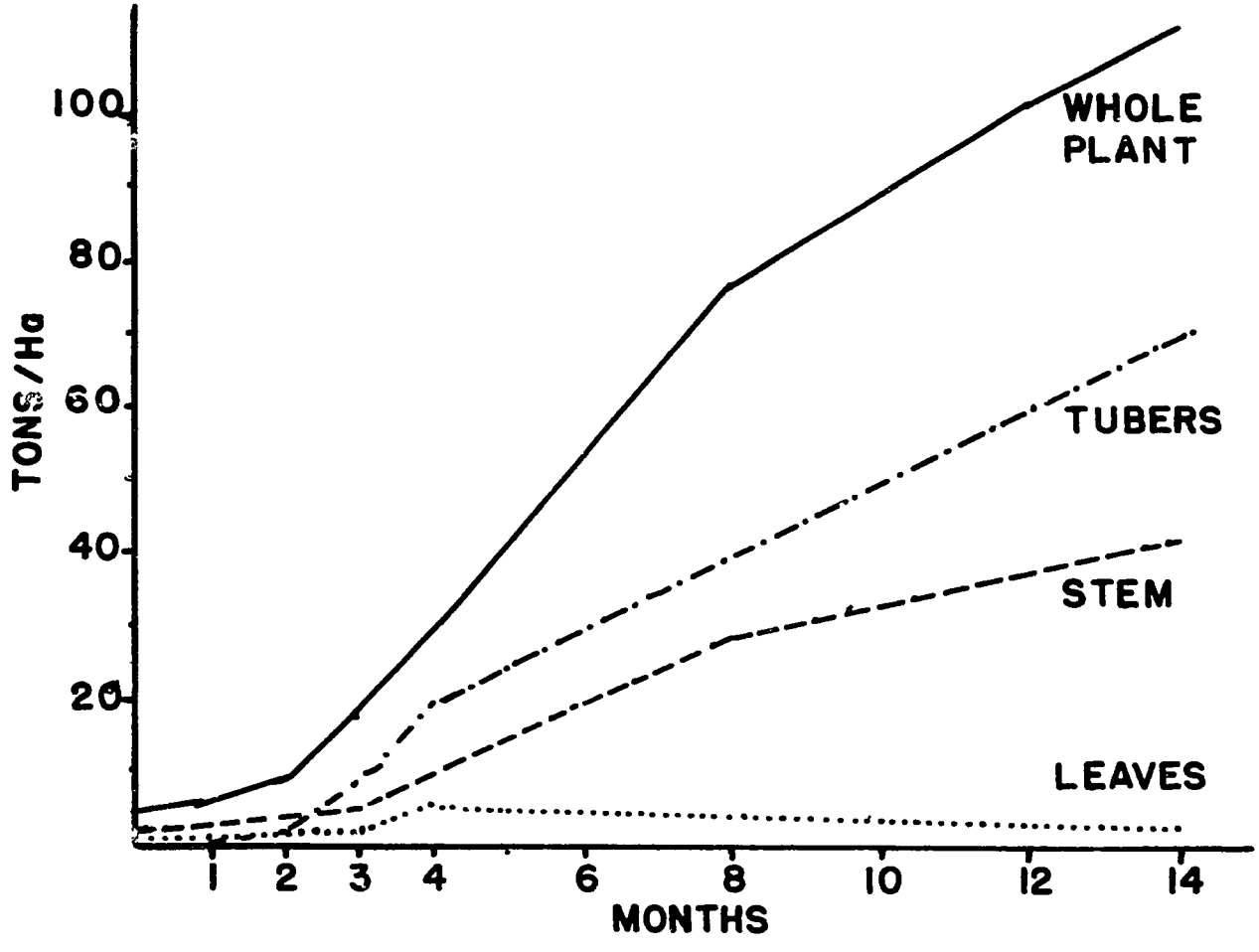
MINERAL NUTRITION AND FERTILIZATION

Nutrient Uptake:

Cassava is well known not only for producing large quantities of carbohydrates, but also for exhausting the soils. The amount of nutrients taken up by the plant increases rapidly from the second month of growth and reaches a maximum for most of the elements at the age of 10-14 months (541). With nitrogen the uptake reaches a maximum at 10 months, whereas in the case of phosphate and potassium the maximum uptake is observed at 14 months age. The rate of production of organic matter in the plant in the course of the growing period corresponds with that of the nutrient uptake, as can be noticed in Figure 3-1, showing also a rapid increase starting at the age of 2 months, except in the leaves.

Among the various nutrients removed from the soil, especially potassium is taken up in large quantities by the cassava plant. The extraordinary potassium requirement of cassava can be noticed from the data in Table 3-5. However, root yields seem to be more affected by adequate phosphate and nitrogen supply, rather than by high potassium supply. It was reported from results of hydroponic and sand cultures of cassava (431, 484) that high potassium levels did not favor tuber production, although it was observed that the weight of the roots decreased by omission of K and low levels of N in the nutrient solutions (431, 432). The major effect on root yield was due to increasing the amount of phosphate, while at adequate phosphate levels, nitrogen was a limiting factor. The greatest tuber production is associated with 1:1 top to tuber ratio and a high P level. The high P response is considered to involve metabolic processes of the young plants in mobilizing the

FIG.3-1 ORGANIC MATTER PRODUCTION IN THE CASSAVA PLANT



Source: J. A. Nijholt (541)

TABLE 3-5. Average nutrient removal by 14-month-old cassava plants.

Yield/ha	Removal kg/ha				
	N	P	K	Ca	Mg
52,000 kg leaves and stems	64	19	176	102	26
59,000 kg roots	42	28	291	43	19
Whole plant	106	47	467	145	45

Source: J. A. Nijholt (541) and J. W. Van Dijk (234)

reserve carbohydrates (phosphorylation) for their vegetative growth (485). Adequate amounts of N are needed for the growth of the plant, since both height and weight of the plant are drastically reduced when N is omitted from the nutrient solution (432). High levels of N in the nutrient solution decreases the starch but increases the protein content of the roots (485). Potassium seems to have an important role in controlling the glucoside content of the roots. As investigated by Bolhuis (119), bitterness and toxicity of cassava are promoted by deficiency in potassium as well as by drought periods. In this respect nitrogen can also be a factor, but the relationship between soil N and the degree of root toxicity is still lacking evidence.

Fertilization:

From the discussion above and from the results of many field experiments conducted in Latin America, Africa and Asia the necessity for the application of at least three major nutrients, N, P and K, is apparent for obtaining good root yields in cassava cultivation (Table 3-6). Omission of N and P may decrease the protein content and the tuber yield, while lack of K may reduce plant growth and weight of tubers. In Sao Paulo (547) an increase of 85-88% over the control is obtained by NPK fertilization (Table 3-7), whereas N, P and K alone have resulted in a yield increase of only 8.8, 35.4 and 2.6%, respectively, over the control. In Madagascar and Vietnam the highest yield is also obtained with a balanced complete treatment with NPK (202, 386). Experiments in Costa Rica (7) support these results by showing the presence of a close interaction between N, P and K fertilization, resulting in maximum tuber yields. The importance of

TABLE 3-6. Root yields (metric tons/ha) in fertilizer experiments conducted in various countries.

Country (NPK kg/ha)	0	NK	PK	NP	NPK
Brazil Sao Paulo (80-120-60)	11.3	13.9	16.9	19.1	21.0
Madagascar (33-96-90)	32.5	38.7	39.9	40.0	40.5
Vietnam (40-75-70)	10.0	12.9	10.5	12.3	15.2
Indonesia (45-40-100)	10.7	20.8	-	9.0	33.6

Source: G. Cours (202); T. Jacoby (386); E. S. Normanha and A. S. Pereira (547) and J. W. Van Dijk (234)

TABLE 3-7. Yields (metric tons/ha) in long-term fertilizer experiments (1923-1940) with selected tropical crops in Indonesia.

Treatment kg/ha	Cassava roots	Unhulled rice	Peanut	Corn grain	Soybean seeds
45 N	10.7	0.60	0.48	0.10	0.05
45-40 NP	9.0	0.32	0.53	0.20	0.05
45-100 NK	20.8	1.14	0.73	0.23	0.11
45-40-100 NPK	33.0	1.22	1.27	1.29	0.39
NPK + Ca	33.6	1.24	1.37	1.56	0.46

Source: J. W. Van Dijk (234)

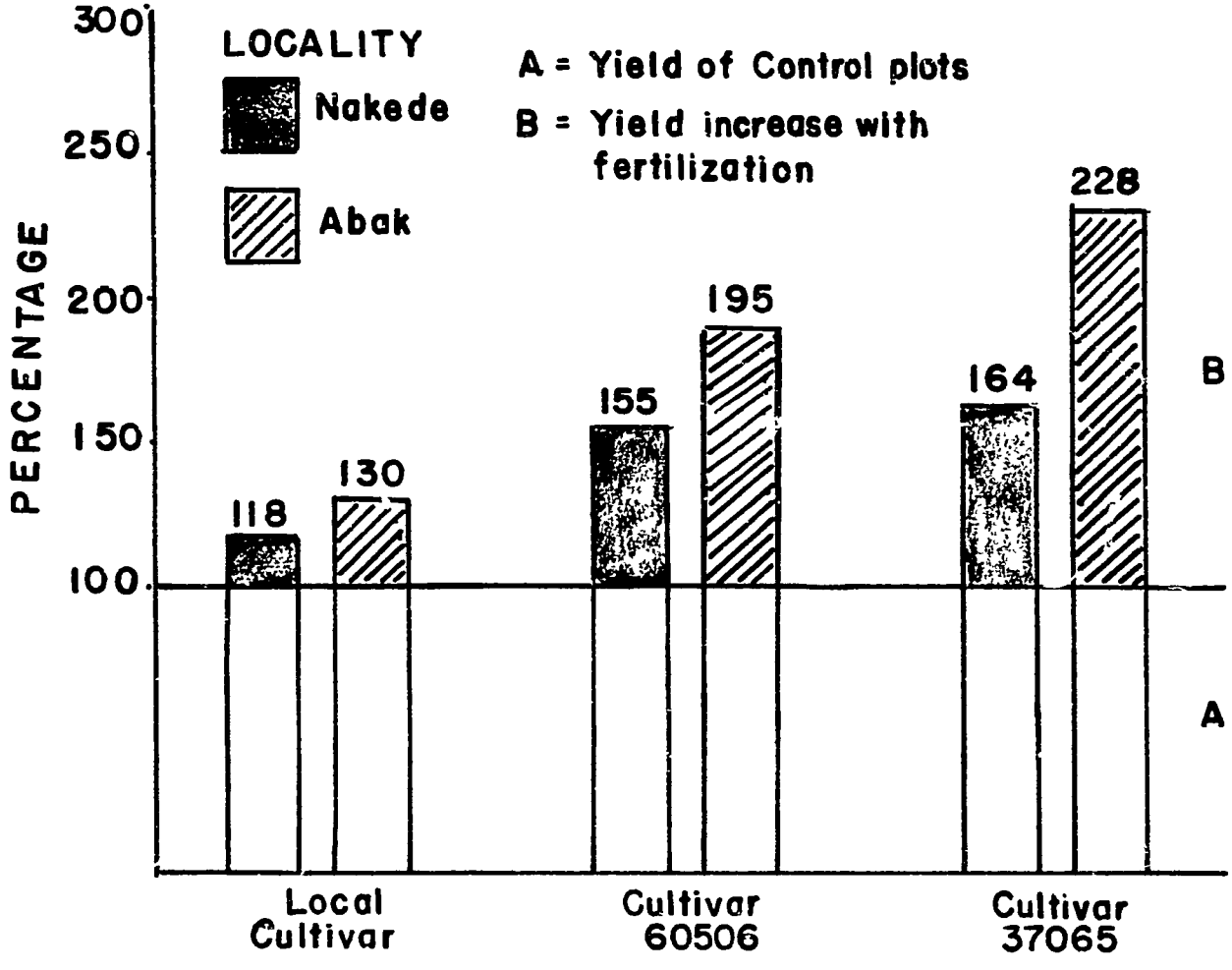
complete fertilization of cassava is reflected also in results of investigations conducted in Indonesia, where in long-term experiments from 1923 to 1940 (234) the highest root yield is obtained by the application NPK.

Concerning the effect of fertilization with the other macronutrients, micronutrients and the use of green manure on cassava yields, not much is known at present and this problem is still open for investigation. Perhaps only for Ca and the use of Crotalaria spp. as green manure, a few limited reports have been published in Indonesia (234), stating that Ca may have some effect on root yields (Table 3-7), while Crotalaria is a suitable replacement for inorganic N fertilizers. Plowed under and incorporated into the soil, Crotalaria in combination with PK fertilization has the same effect as inorganic NPK supply to the cassava plant.

Apart from the nutrient content of the soil and climatic limitations, the yield of cassava is also determined to a large extent by the variety grown. As is the case with other crops, low and high yielding cassava varieties are present among the many cultivars available. Figure 3-2 illustrates the different response of three different cultivars to a similar treatment of 300 kg of a 10-10-20 fertilizer in two locations in Nigeria (386).

Finally, it should be mentioned that fertilization may increase the quality of cassava roots only to a certain extent. Plant breeding should also be conducted to develop new high yielding varieties, containing or introducing high protein, starch and mineral contents. High protein content in starchy root crops is not the general case, but it has been

FIG.3-2 EFFECT OF DIFFERENT CULTIVARS ON ROOT YIELDS IN NIGERIA



Source: T. Jacoby (386)

reported that some varieties in Cambodia and Viet-Nam have protein contents amounting to 3.5% in the roots, and in Surinam (426) it has been found that Manihot saxicola L. contains 12% protein besides high amounts of HCN. Colombia has reported a variety with 7.5% protein (486). Whether or not this high protein content in roots has been verified is not known but should certainly be investigated.

The yields of cassava roots as discussed above are unparalleled in size compared with other major tropical food crops. Grown under similar conditions on Oxisols and completely fertilized, the cassava yield in Indonesia is approximately 25 times that of rice, corn and peanut (Table 3-7). Its potential contribution to the world food supply with a relatively easy culture is thus without question, especially if new high yielding varieties with low HCN and high protein, starch and mineral contents can be obtained. Varieties with low HCN content are available but not commonly grown since their yield potential is very low and farmers have long since learned that most of the HCN could be liberated easily and thus make an acceptable food.

DISEASES AND PEST CONTROL

Cassava is seldom affected by serious pests and diseases. (See Chapter IV for a more complete discussion of pests and diseases.) This is thought to be associated with the high HCN content. However, occasionally it may be damaged by certain insects and diseases. In this respect a distinction can be made between groups attacking the parts of the plant above the ground, the roots and the stored product.

The parts of the plant above the ground, especially the leaves, may be affected in the dry season by the red cassava mite (Tetranychus telarius), which lives underneath the leaves. The leaves may become yellow and drop off, thus reducing carbohydrate formation. When the soil is sufficiently moist, repeated new leaf formation may decrease the effect of mite infestation. Spraying with insecticides is too expensive, considering the present low prices offered for cassava roots except as it might be used to control initial spots of infestation.

Scales, mealy bugs and others, and also Dasymus manihotis Blote in Indonesia are sometimes found to be harmful, while in new planted cuttings, termites and fungi may become active, however, damage is frequently on a limited scale. In 1967, a report came from St. Croix, U.S. Virgin Islands (433), describing the infestation of cassava by hornworms or larvae of the sphingid Erinnys alope Drury. Spraying with any suitable insecticide, such as DDT or Sevin, has proven to be successful.

A more serious problem for the parts above the ground is the mosaic disease, caused by a virus, and manifested in lightspotted or mottled curly leaves. Control methods include destroying the vector and affected plants, selection and breeding of mosaic-resistant varieties of cassava.

The roots are also not free from pests and diseases. The larvae of the beetle Leucopholis rorida Fab. feeds on fresh cassava roots, which can be noticed from wilting symptoms of the plant. No control methods have been tried, except manual collection and destruction of the larvae. However, wilting can also be induced by Pseudomonas solanacearum E.F.S., which may sometimes cause serious damage in cassava stands.

Occasionally monkeys, wild pigs, porcupines, rats and elephants have been reported troublesome, the latter especially in Africa (162). In Indonesia, wild dogs have also been known to root out cassava roots (426).

In the stored product, the beetles Lasioderma sp. and Tribolium sp., and other "storage" insects and fungi are harmful for tapioca flour, cassava chips or "gaplek" and gaplek meal.

OPERATION ECONOMY

Cassava production using existing simple techniques, involving negligible capital investment, is economic in countries where the labor is prepared to accept a low standard of living. Like many other tropical food crops, in those countries cassava is still cultivated largely by the farmers and plantations using manual methods. Data on the economics of producing cassava have seldom been documented, and those available show labor requirements varying considerably from country to country. This is illustrated with the data in Table 3-8, which show that cassava cultivation in Indonesia requires approximately 4 times more labor work per hectare than in Jamaica (269, 426). The figures reported for Indonesia are indeed high, but results of investigations in the Philippines (158, 160) seem to support these, since it has been observed in the latter country that 111 working-days/ha (666 man-hours/ha) are required only for manual harvest of the roots. On the other hand, the labor input stated for Jamaica is supported by Krochmal (429), who shows for Latin America and the Caribbean region similar labor requirements as mentioned for Jamaica, e.g., 62.5 working-days/ha (500 man-hours/ha). Such a large difference in labor input must be due in part to the

TABLE 3-8. Estimated labor requirements per hectare of crops in 6-8 hours working days.

Crop	Indonesia	Jamaica
Cassava	300	77-89
Sweet potatoes	532	127-141
Yams	-	329-460
Irish potatoes	554	-

Source: D. T. Edwards and J. Cropper (269) and A. J. Koens (426)

different methods and standards employed in the countries involved. As can be noticed, the units for working-days are based on a 6-hour work day in Asia versus an 8-hour working day in Latin America.

Compared with a few selected food crops grown under similar conditions as with cassava, the data in Table 3-8 also show that the labor input for cassava is approximately 1 1/2 to 2 times lower than that for sweet potatoes and Irish potatoes in Indonesia, and 3 to 4 times smaller than that for sweet potatoes and yams grown in Jamaica. These data illustrate the relatively lower labor requirements of cassava compared to other crops, when cultivated under similar conditions. The estimated cost in man-hours per ton of yield will even drop considerably for cassava, considering its potential of being able to produce 50 tons/ha. The data in Table 3-9 show the estimated cost in man-hours/ton for cassava, yams and Irish potatoes, the latter grown in Europe with semi-mechanized methods (203). It can be noticed that the estimated cost for cassava with manual labor and based on a production of 50 tons/ha is approximately 10 times lower than that for the production of yams, however, it is 2 times higher than the estimated cost per ton of Irish potatoes in Europe. Consequently, if cassava production is to be developed in the changing economic matrix of countries, where people are progressively asking higher standards of living, something needs to be done in the improvement and mechanization of cultural techniques. Complete mechanization of cassava cultivation in Latin America (429) has shown to drop the labor input from 500 to 110 man-hours/ha, while in the Philippines for the harvest only, mechanization can drop the labor requirements from 666 to 16 man-hours/ha

TABLE 3-9. Estimated cost of production in man-hours/ton (not included are animal and tractor hours).

Crop	Man-hours/ton	
Cassava, manual[1]	180	(based on 10 tons/ha)
Cassava, manual[1]	36	(based on 50 tons/ha)
Yams, manual[2]	380	
Irish potatoes, semi-mechanized[2]	18	

Source: [1]Calculated by author
[2]D. G. Coursey (203)

(158). This means that in Latin America 2.2 man-hours/ha or lower are required for the production of 1 ton of cassava (based on a yield of 50 tons/ha), which must be considered low, even for European and U.S. standards.

In conclusion, it should be mentioned that cassava will probably always be very important as a subsistence crop to those laborers who raise it for their own food while working during the day at some other form of income endeavor.

RECOMMENDED AGRONOMIC RESEARCH

An active agronomic research program on cassava is needed and should be initiated as soon as possible. The primary objective of the program would be to increase yields/ha economically.

Considerable emphasis should be placed on soil and water management practices, particularly on dry or droughty soils since the crop is adapted to dry areas. Attention should be given to the relationship between essential elements in the soil solution and yield. An over- or under-supply will result in reduced yields. A continuous supply in dilute solution is essential and therefore slow release fertilizers should be incorporated into the research and management program.

Research emphasis should also be placed on determining the optimum soil moisture requirement, soil pH, nutrient requirements, and stand density on the better cultivars in each of the 3 continents of the world (Africa, Asia and South America). The cost of production in terms of planting, weeding, insect and disease control, and harvesting should be tabulated in cooperation with an economist and efforts made to

reduce production cost to the point where cassava can be produced for processing of starch or chips for export and/or utilized in animal feeds.

Since cassava soils are extremely variable in origin, texture, fertility, etc., all field research should be coordinated with the soil specialist before initiation.

CHAPTER IV

Insect and Diseases of Cassava[1]

When man has attempted to change his patterns of agriculture intensive monoculture, plant breeding, and cultural practices, he sometimes unwittingly creates conditions which favor destructive epidemics by pathogenic organisms and insects. It is often stated that cassava has fewer diseases and insect pests than other crops. While numerous field observations indicate that cassava may have unique inherent resistance to disease and insect pests, this observation must also be evaluated in light of the traditional methods of cultivating the crop, and the losses that disease and insects cause on other crops, which are compared with cassava. The shifting cultivation associated with the "door-yard" method of growing cassava may limit epidemics of certain diseases and insects. Compared to other crops, less effort has been made in defining the insect and disease problems on cassava and the methods of controlling them. This probably, in part, reflects that the predominately poorer small land owners, who traditionally cultivate cassava as a "door-yard" subsistence crop, exert less pressure for research than do the larger land owners, who grow cash crops and are more aware of the losses due to disease and insects. Cassava, however, is certainly not free of disease and insect pests. A review of the literature indicates at least 40 different organisms that can cause disease on cassava. If cassava is compared with other crops in the

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[1]Prepared by P. S. Lehman, Department of Plant Pathology and Genetics, University of Georgia, Athens, Georgia.

tropics, it must be considered that generally diseases and insects cause much greater losses in the tropics. Wellman (824) has compared the number of diseases attacking crops that were grown under intensive cultivation in both tropical and temperature regions and has found the number of diseases to be five to ten times greater in the tropics. Thus, even though there is general agreement that due to inherent qualities cassava has fewer insect pests and diseases than other tropical crops, any valid conclusion regarding the potential threat that diseases and insect pests may pose to intensive and extensive production of cassava, will be dependent on further definition of disease and insect problems of cassava, and on further knowledge of how altering the patterns of cultivating the crop affects insect populations and disease epidemics.

NATURE AND EXTENT OF INSECT PROBLEMS

Description of Prevalent Insect Problems:

There appear to be no major pantropical insect pests on cassava. However, insects have been reported to locally limit production, especially under intensive cultivation of cassava.

Hornworms.--These caterpillars, sphingids belonging to the genus *Erinnyis*, are sometimes extremely destructive on cassava. This pest has been reported in Brazil (305, 451, 546), Colombia (277), Venezuela (68), and the Virgin Islands (433). A general increase in this pest has been noted in areas where there has been extensive and intensive culture of cassava (701). Occasionally, these caterpillars completely defoliate cassava, for example, in Brazil this pest denuded all the foliage of more than 1,000 hectares of cassava in less than a week (77). The

larvae also probably transmit bacterial wilt from plant to plant (546). Several natural enemies of the eggs and caterpillars of Erinnyis have been described (306, 661, 705). The importance of these parasites and their potential in biological control has not been determined.

Spider Mites.--The red spider mite, Tetranychus telarius, is one of the most widespread insect pests on cassava. Oei-Dharma (554) in Indonesia reported that plants that were severely attacked were stunted, the younger leaves were often wilted, and the older leaves developed red-brown patches. In Brazil the spider mite is primarily a problem in the northeastern states with a hot dry climate, and if it is not controlled, it may in some cases cause defoliation (122, 546). Tetranychus species have also been reported as pests of cassava in Colombia (278), Ghana (317), Haiti (494), Malaysia (347), Mozambique (637), Puerto Rico (494), St. Kitts (494), Taiwan (741), and Trinidad (299).

Stem Borers.--The larvae of certain weevils, mostly belonging to the genus Coelosternus, are reported to cause serious loss of planting material and decrease root quality and production in Brazil, Puerto Rico and the West Indies (513, 514, 546). The adult beetles deposit their eggs on the young stems and the larvae damage the stem as they bore into the pith and xylem of the stem. The adult weevils feed on the tips of young shoots and may retard growth (317). In Brazil importance of stem borers varies greatly from year to year and with locality. In Africa, Lefevre (447) reported that the stem borer, Heterobostrychus brunneus, was one of the most harmful insects on cassava. He also reported stem borers from six other genera that were pests on cassava.

Scale Insects.--In Ghana (241, 832) and India (55), and scale insect *Aonidomytelus albus* attacks cassava causing chloroses and aggravating the effect of drought. Other scale insects, *Saissetia* sp. and *Lepidosaphes* sp., have been reported as pests on cassava in Brazil (451), Dominican Republic (336), Indonesia (554), and the Madagasy Republic (314).

Shoot Flies.--In Brazil several species of flies, *Silba pendula* Bezzi and *Antherigona excisa*, damage the terminal portions of the stems of certain cultivars of cassava (546, 549).

Termites and Ants.--Occasionally termites destroy newly planted stems (525, 549), and leaf-cutting ants, belonging to the genus *Atta*, sometimes defoliate cassava (546, 709).

Locusts.--Cassava is one of the few crops that is free from the ravages of the migratory African locust, *Locusta migratoria migratorioides* (399, 409). Other locusts, *Zonocerus variegatus* and *Z. elegans*, do defoliate cassava when other vegetation is scarce in dry seasons, but new shoots are usually produced after the attack (361, 399, 689, 808).

Storage Insects.--When cassava is stored commercially as dried chips, control of storage insects is mandatory. Frappa (314) listed 13 genera of insects that were pests of dried stored cassava in Madagascar. Pingale et al. (603) found nine different species of insects capable of causing damage to stored cassava chips.

Effect of Insects on Yield:

For most of the insect pests mentioned above, researchers have made qualitative statements that severe attacks by these pests will

reduce cassava yields. However, few quantitative evaluations of actual losses have been made, except for storage losses. Pingale et al. (603) reported that insects frequently reduce cassava chips to dust in about four to five months. They introduced insects, most of which were previously found in cassava warehouses, to bins containing 45 kilos of dried cassava chips, and studied insect reproduction and the damage these insects caused to stored cassava chips during a three-month period (Table 4-1). Among the insects tested, Araecerus fasciculatus and Stegobium paniceum were the most destructive, damaging 100% and 58% of the stored chips, respectively.

Present Status of Insect-pest Control:

Some of the control practices that have been recommended are summarized in Table 4-2. For cassava, as with other crops, although damage due to insect pests usually increases with extensive and intensive culture, labor and equipment costs of pest control decreases per plant, so the returns per hectare for a control practice increases to a level where chemical control becomes more feasible.

In the traditional "door-yard" method of cultivating cassava, chemical control usually has not been practiced nor is it considered economically justified unless losses due to insects are unusually severe. For this reason more effort should be made to develop control based on cultural practices and host resistance to insect pests. In Brazil, cultivars that are partially resistant to stem borers have been found (546) and a program involving the selection of cultivars resistant to the shoot fly, Silba pendula, is currently underway (Pereira, personal communication).

TABLE 4-1. Damage Caused by Insects to Dry Tapioca Chips in Storage.

Insect	Average adult population/50 kg of chips	Proportion of damaged chips (%)	Proportion of dust to chips (%)
Araecerus fasciculatus	419	100	34.8
Stegobium paniceum	317	58	7.8
Oryzaephilus surinamensis	112	0	1.2
Ephestia cautella	52	2	0.5
Corcyra cephalonica	29	1	0.3
Tenebroides mauritanicus	18	1	0.2
Alphitobius diaperinus	18	0	0.2
Laemophloeus minutus	18	0	0.0
Rhizopertha dominica	17	2	3.4
Tribolium castaneum	--	0	0.7

Source: Pingale et al. (603)

TABLE 4-2. Recommended Control Practices for Insect Pests of Cassava.

Insect pest	Recommended control practice
HORNWORMS	
Erinnyis ello	0.1% or 0.05% dinitro-o-cyclohexylphenol (451); 10% w.p. DDT or 20% Toxaphene (58) (549); dusting with 1.5% Endrin, 7.5% Sevin (549); Telodrex, 7 cc/liter water (278), DDT or Sevin (433).
Erinnyis alope	DDT or Sevin (433).
SPIDER MITES	
Tetranychus telarius	Sulfur dust (347); 5% mixture of sulfur and lime with soap; 0.8% white spraying oil; 0.02% Folidol E605 46.7% EC; Toxaphene 50% EC + Rotenone (0.3% + 0.5%); Roxion, 500 cc/hectuare or Kelthane A.P. at 4 kilograms/hectare (277).
STEM BORERS	
Coelosternus sp. (*C. rugicollis*, *C. granicollis*, *C. manihoti*, *C. notaticeps*)	Destruction of stems after harvest and crop rotation (514); use of less susceptible cultivars (546).

TABLE 4-2. (continued)

Insect pest	Recommended control practice
SCALE INSECTS	
Aonidomytilus sp.	Spraying or dipping in 0.1% Meta-systox; 0.05% Parathion; or 0.1% Malathion (687).
Saissetia nigra	8-10% Carbolineum Plantarium; 0.02% Folidol E605 46% EC (554).
SHOOT FLIES	
Silba pendula and *Antherigona excisa*	DDT or Telodrex (277); spray with mixture of 200 g dieldrin 50% w.p., 5 kg of sugar in 100 liters water (549); resistant varieties (Pereira, pers. comm. 1971).
TERMITES	Benzene hexachloride 1.0%, aldrin 2.5%; 10% Canfeno Clorado 10% (549).
STORAGE PESTS	
Araecerus fasciculatus *Stegobium paniceum*	Fumigation with methyl bromide or ethylene dibromide; impregnation of storage bags with Lindane-dieldrin mixture (603).

NATURE AND PREVALENCE OF DISEASES

Description of Prevalent Diseases:

Viruses.--Based on the literature currently available, viruses are considered the greatest threat to cassava production. Cassava mosaic was first reported in East Africa by Warburg in 1894, and since that time it has been found in almost all the countries of Africa where cassava is grown (398), in Brazil (195), Indonesia (530) and India (20). Although the symptoms expressed following infection with mosaic virus may vary considerably, severe infection generally results in chlorosis of discrete areas of the laminae, distortion of the leaves and a reduction in the size of the leaves. Chant and Beck (170) have shown that chloroplasts of infected cells are abnormal and fewer in number, intercellular air spaces are reduced in number, and the palisade layer does not differentiate normally. These anatomical changes are associated with a decrease in photosynthetic rates and an increase in respiratory rates, that result in an overall net loss in carbohydrates and in lower yields (97). Factors that may influence the symptoms expressed following cassava mosaic virus infection are: host genetic variation, host age at the time of infection, environmental factors such as temperature and rainfall, and virus strains. Based on the variable symptoms produced on the same cultivars of cassava, Storey and Nichols (724) divided the Tanganian mosaic virus into a severe strain and a mild strain. Kitajima and Costa (421) have compared the mosaic viruses from infected plants in West Africa with the mosaic virus in Brazil. The virus in Africa is apparently spherical, whereas the common cassava mosaic virus in Brazil is a long flexuous rod, 480-580 mμ. This indicates that there are

several different viruses that produce similar mosaic symptoms on cassava, and that a more critical comparison is needed to establish how many different viruses or strains are present throughout the world. Since cassava is normally propagated vegetatively from stem cuttings, this disease is spread if infected cuttings are planted. Jameson (388) has noted that in East Africa in times of drought or food scarcity, the incidence of mosaic disease greatly increased since people ate the best of the crop and used the poorer remnant plants for propagation. In Africa, the white fly, Bemisia tabaci, has been shown to transmit the virus from diseased to healthy plants (168, 725). The insect transmits the virus only to young leaves which are less than 25% of their mature length (725).

Another virus disease, known as brown streak, occurs only on the east coast of Africa (396, 398, 539). The virus, if severe, may cause plant death, but the symptoms are exceedingly variable in frequency and intensity (539). Leaf chlorosis or mosaic frequently occurs, but except for severe infections, only mature leaves are affected, so there is no leaf distortion. Other symptoms that occur are necrosis of the root-storage tissue and in some cases brown lesions occur on the stem. The brown streak virus is about 600 mμ long and rod-shaped (421). In the field the virus is transmitted by vegetative propagation. Lister (456) has also transmitted it mechanically to several hosts. Although Storey (720) suspected that the virus may be transmitted by white flies, Bemisia, there has been no research that has conclusively shown that insects are vectors of this virus.

Mycoplasma.--In Brazil, a disease of cassava known as "witches' broom" occasionally caused high losses, especially in large plantations (253). Originally this disease was thought to be caused by a virus, but the causal agent is now known to be a mycoplasma or Pleuropneumonia-like organism (Pereira, personal communication). In addition to causing numerous abnormally developed stem-sprouts, this organism reduces plant growth and starch content of the roots (546).

Bacteria.--Bacterial wilt caused by Xanthomonas manihotis is a serious disease in limited areas of Brazil and Argentina (546, 663, 847). Infection of the vascular system by this pathogen causes wilting and may greatly decrease root production. Angular leaf spot is also caused by this organism. Defoliation due to this disease has been reported in the Pacific coastal regions of Guatemala (546).

A bacterial wilt caused by a Pseudomonas sp. has been observed in the majority of the plantations in central and northern Colombia. Symptoms of the disease are grey-maroon leaf spots, stem cankers, and vascular necrosis. Infection is thought to occur through the stomates. The bacteria advance to the vascular system and cause wilting and death of young plants. A yellowish exudate containing bacteria is emitted from the stem cankers, from which the bacteria are dispersed (463).

Fungi.--Brown leaf spot caused by Cercospora henningsii has been found in the majority of countries where cassava is grown. White leaf spot caused by Cercospora caribaea is not as widely distributed and of lesser importance. Both pathogens primarily infect mature leaves; only rarely do they cause severe defoliation. Other foliar fungi that are pathogenic on cassava, but are usually considered of minor importance

are: Glomerella cingulata causing anthracnose or whithertip (444, 832); leaf and stem rust caused by several species of Uromyces (317, 444, 736); ash leaf spot caused by Oidium manihotis (539); and powdery mildew caused by Microsphaera euphorbiae (Wellman, personal communication). A vascular wilt caused by Verticillium dahliae is reported to be a sporadic problem in Ghana (356).

A number of fungi cause root or tuber rots of cassava in the field. White thread, a disease caused by Fomes lignosus, is reported to be widespread in Ghana (241, 832). It has also been reported in Ceylon (737), Malaysia (822), and Thailand (404). Wellman (personal communication) has also observed it to be a problem in new clearings in Equador. The fungus affects mature tubers, which become covered with a network of white mycellium, which is the reason the disease is commonly known as white thread in Ghana. It is reported to cause a wet-rot of the tubers, and it becomes even more severe after harvest and may destroy the tubers in a few days. Other fungi reported pathogenic on roots of cassava are Fusarium sp. (769), Phytophthora parasitica (297, 409), and Rosellinia sp. (155, 252, 444, 795). In storage, fresh cassava roots are subject to soft rot which has been attributed to various species of Penicillium, Aspergillis, Rhizopus, and several species of bacteria (483, 732).

An abiotic problem associated with stored cassava roots is known as vascular streaking. After the tubers are harvested, a dark bluish discoloration of the vascular bundles starts from the cut surface and rapidly progresses inward. In a few days, the discoloration is usually so severe that the tubers are unsuitable for the fresh market. Attempts to isolate fungi and bacteria from the leading edge of the discolored

vascular tissue have been negative (75). The cause of the discoloration is thought to be physiological or due to oxidative enzymatic degradation (75, 76, 548). Vascular streaking has been recognized as an acute post-harvest problem in Brazil, Costa Rica and Florida, U.S.A. (75, 246, 548). However, in many other parts of the world it has been a long accepted practice to harvest only tubers that can be used immediately, which indicates that rapid spoilage due either to vascular streaking or micro-organisms is a very widespread problem (409, 765).

Nematodes.--At least fourteen species of nematodes are known to be parasitic on cassava roots. In the Ivory Coast where cassava is simultaneously grown in the same field with okra and eggplant, root-knot caused by *Meloidogyne incognita* is a serious disease of cassava (464). The lesion nematode, *Pratylenchus brachyurus*, and the spiral nematode, *Helicotylenchus erythrinae*, are frequently found on cassava in Togo (350). In Jamaica high population densities of the reniform nematode, *Rotylenchulus reniformis*, which causes damage on many other tropical crops, have been found on cassava (236). *Meloidogyne* and *Rotylenchulus* have also been found on cassava in Nigeria (R. A. Odihirin, personal communication).

Effect of Diseases on Yield and Quality:

The most extensive attempt to analyze the effect of any disease on yields of cassava has been the studies in Africa on losses due to cassava mosaic. Based on Table 4-3, which is a summary of the research on the effect of the mosaic virus on yield (398), it is apparent that even though estimates vary greatly, virus diseases do reduce cassava yields. These different estimates are likely due to variation in virulence of

TABLE 4-3. The Effect of Virus Infection on Cassava Yield.

Area		Estimated yield loss due to virus infection[1]	Authority
		(%)	
Congo		20	Muller, 1931
Nigeria	(a)	33	Golding, 1936
	(b)	43	
Nigeria		34	Beck and Chant, 1958
Nigeria	(a)	33	Ekandem, 1964
	(b)	14.5%	
Madagascar	(a)	83	Cours, 1951
	(b)	nil	
Zanzibar		76	Tidbury, 1937
Zanzibar		95	Briant and Johns, 1940
Tanzania	(a)	65	Jennings, 1960
	(b)	16	

[1]Results listed (a) are for plants or cultivars which had more severe symptoms than (b).

Source: Jennings (398)

virus strains, variation in resistance of cassava cultivars to the virus, and variation at the different locations due to environmental influences on the host, virus, and vectors. Plant age at the time of infection is another factor that greatly influences the effect that the mosaic virus has on yield. In Tanzania, Briant and Johns (137) found that the most serious reduction in yield results from primary infection that occurs when infected plants are propagated vegetatively. Secondary infection, through insect transmission after cassava is established, has much less effect on yield.

Reliable estimates of reduction in yield due to the brown streak virus are not available. It is not usually possible to accurately estimate the losses due to brown streak because diseased stocks also often carry cassava mosaic virus. The higher estimates of losses due to viruses on the coast of East Africa are probably due to the presence of both viruses (398). Although his study was not primarily related to yield, Nichols (539) reported that the brown streak virus may cause severe stunting of very susceptible plants and a reduction in root growth. However, infection of established plants apparently did not reduce yield. The reduction in quality of the tubers is often of more importance than the reduction in yield. Severe infection by this virus causes internal necrosis of the tubers, so that they are of little economic value.

Information on the influence of other disease organisms on yield is very meager. Fomes lignosis is reported to cause losses up to 20% in Ghana. Losses due to nematodes in Togo, West Africa, were reported in one case to be approximately 7% (464). Leaf spot caused by Cercospora is very widespread, but since it primarily attacks mature foliage, it is

generally considered to be of minor importance. However, this evaluation is based primarily on observation rather than experimental data. Since fungi such as Phytopthora, Fusarium, and Verticillium, and nematodes, such as Meloidogyne and Rotylenchulus, cause serious damage on other crops, critical experimental evaluations are needed to determine the potential that these organisms have on the reduction of cassava yield.

Although data for a critical comparison is lacking, it appears that storage losses may be a much greater threat to extensive production than would be the reduction in yield due to diseases. Majumder et al. (483) states that the short storage life of cassava tubers is a limiting factor in handling large quantities because the fresh tubers start rotting in 2-3 days after harvest, and soon become unsuitable for industrial use and human consumption. After initiating a relatively large-scale production of cassava, one grower in Costa Rica found that it was not possible to market the cassava in the nearby city of San Jose because of excessive deterioration of the tubers enroute to market. Similar problems have been experienced by small growers in Colombia (Averre, personal communication). Cassava that was grown in Florida, U.S.A., and was shipped to New York in wooden crates containing moist sawdust, was rejected in New York because extensive decay and discoloration of the tubers occurred during the 3 to 4 days of transport. Although these may be isolated cases and appear unimportant, it is felt that the magnitude of the post-harvest problems of cassava has not been appreciated or fully evaluated. This may be partially associated with the fact that the "backdoor" producers do not usually dig more tubers than can be used or sold in a few days. Obviously, such a practice

will not be compatible with large-scale commercial marketing of cassava for human and industrial consumption.

Present Status of Disease Control Measures:

Screening of cultivar collections and breeding for mosaic virus resistance has been attempted in Ghana, Nigeria and Tanzania (237, 241, 242, 272, 393, 395, 536). Nichols (536) succeeded in selecting cultivars with improved resistance and good yield. Jameson (388) reported a relatively successful mosaic control program in Uganda that consisted of distributing moderately resistant cultivars followed by the roguing of diseased plants. In some cases the latter practice was enforced by the District Councils who passed laws requiring the removal of mosaic-infected plants. However, cultivars that showed moderate resistance in in land Uganda were susceptible in the coastal regions of East Africa. Jennings (393) was successful in developing cultivars for this region which he described as having near-immunity, but he was not able to incorporate satisfactory yield into these lines. In addition to low yield other factors, such as palatability and tradition, have led growers to reject virus resistant cultivars. In northwest Uganda cassava is left in the ground for 2-3 years and under these conditions rot-resistant cultivars are required, but none of the mosaic-resistant cultivars possessed this characteristic and, consequently, were not accepted by growers.

Breeding for resistance to brown streak virus has been conducted in East Africa. Jennings (393, 398) was able to develop highly resistant hybrids by crossing Manihot esculenta with Manihot melanobasis. These hybrids were promising for yield and had double the protein content of

ordinary cassava. However, none of these have been released to local growers because the breeding program was discontinued partially due to political changes.

White thread, caused by Fomes lignosus, can be partially controlled by early harvest, since mature tubers are most susceptible to the fungus. Doku (241) reported that no differences in resistance were found among the cultivars that he tested.

Brown leaf spot can be controlled with Bordeaux mixture, but in most cases control is not required (317).

Cultivars having at least partial resistance to bacterial wilt, caused by Xanthomonas manihotis, have been found and these are now widely used in Brazil (253, 547, 663). In Colombia, screening tests have indicated that certain cultivars have resistance to foliar penetration by the Pseudomonas sp. that causes bacterial wilt. However, no cultivars were found that had resistance to the bacteria once it became localized in the vascular tissue (463).

Nematodes can be controlled chemically with dibromochloropropane (DBCP) or other nematicides. Since studies have indicated that cultivars of cassava differ widely in resistance to Pratylenchus, it appears that the development of cultivars resistant to nematodes may be feasible and certainly would be more economical than chemical control (464).

Storage rots, particularly those due to Rhizopus, can be chemically controlled with any of the following treatments: ethylene dibromide (EdBr); EdBr and ethyl bromide (EBr) mixture (1:1; v/v); and a formaldehyde treatment (483). Cassava fumigated with EdBr and EBr might be used for human consumption, since the bromide residue was 13-19 ppm. Thus,

chemical control of the storage rots appears feasible.

Experiments indicate that vascular streaking can be controlled through drying (548); refrigeration at 0°-2.5^{o} C and 85-90% relative humidity (548); a pre-storage hot water dip (75); storage of the tubers at high temperature (75), and anerobic storage (76).

RECOMMENDED FUTURE RESEARCH ON DISEASE AND PEST MANAGEMENT

It is estimated that in the coming decades eighty percent of the increase in the world's population will be in the tropics. An expansion of cassava production, the development of high yielding cultivars with high protein and starch content, and greater control of losses due to pests and disease will be necessary to help meet the needs for food in the future. Among the problems relating to disease and pest management of cassava, and in general among the problems relating to cassava production, priority should be given to investigating methods of controlling losses of cassava during storage and marketing. The following reasons are given for considering this a primary priority for research:

1) Post-harvest losses due to microorganisms and physiological degradation presently appear to be a major obstacle for the commercial marketing and export of fresh cassava, as well as the future expansion of cassava production.
2) Based on research to date, the practical solution of this problem appears feasible with limited resources, and the odds for success of such a project should be good.

3) An investment for the solution of this problem would offer high dividends since it would have a position impact at the grass roots level on the economic development of many countries in the tropics.

4) It has been suggested that one approach to solving the storage problem would be through rapid post-harvest drying and storing the cassava as flour or chips. This may offer a partial solution if post-harvest techniques could be developed that would be practical and economical for the grower, and if the end product was acceptable to the consumer. However, with increasing migration of lower economic masses to the larger tropical cities, potentially there will be a growing market for fresh cassava, and a greater need to solve the post-harvest degradation problems of fresh cassava.

Following are some considerations for developing a program to control marketing and storage losses of cassava.

1) Although basic research has been conducted on vascular streaking due to physiological breakdown and microbial degradation of cassava tubers, there is a need for further integrated research on harvesting, storage, and marketing problems. Averre (75) indicated that certain treatments that control vascular streaking caused an increase in soft rot. However, several of these procedures, especially high temperature or anerobic storage combined with limited chemical control of microorganisms might

provide growers with an inexpensive means of controlling losses, so that they could ship cassava to larger markets or processing plants. There is also a need for basic research on differences in resistance of cultivar to vascular streaking and microbial breakdown.

2) Pathologists, food technologists, and agricultural engineers will need to cooperate to develop practical economic control of storage losses for both the small "door-yard" growers and larger commercial growers. Extension personnel will be needed to demonstrate these techniques and help solve problems for individual growers.

The lack of quantitative data on the influence of many insects and diseases on yield indicates a need for further research in this area. There is also a need for international cooperation to compare the cassava viruses and virus strains found in various countries. Research by Kitajama and Costa (421) indicates that several different viruses cause mosaic symptoms on cassava. Confusion in the past has arisen because identification of the viruses has been primarily based on symptoms. Serology and electron microscopy should be used to provide further information on the number of viruses and virus strains present in cassava. This is recommended since such information is a prerequisite for an effective breeding program for virus resistance and is also necessary to help prevent the introduction of new viruses into countries where they currently do not exist.

In tropical areas with strong population pressures, the trend is to be expected toward improving yields through plant breeding, the use of fertilizer and extensive and intensive planting. These changes generally have increased the vulnerability of other plants to disease and insect epidemics and there is evidence that this will also be true for cassava. For example, in certain areas of central Africa where cassava was grown extensively, a rotation of rice, peanuts and cassava was recommended and practiced. At the end of two cycles the average yield of rice and peanuts fell to approximately one-fifth that of the original planting and cassava yields fell to one-third the original yield. The decrease in cassava yields was largely due to root rots caused by Phytopthora which rose from less than 10% in fields newly cleared to 50% at the end of the rotation cycle (409).

The fact that cassava is to a great extent peculiarly free from the ravages of the migratory locust, Locusta migratoria, indicates that it may have some inherent genetic qualities that make it unusually resistant to disease and attack by insects. Furthermore, research is needed to understand if or why cassava is more resistant than other plants. For example, cassava contains a cyanogenic glucoside that may serve as a chemical defense against some diseases and insects. This is supported by the fact that cultivars with high HCN content have fewer disease and insect problems than do cultivars with low HCN content (Pereira, personal communication). Low hydrocyanic acid content is generally considered by plant breeders to be a desirable characteristic. When such objectives are adopted in any breeding program, concurrently an attempt should be made to monitor the effect that decreased HCN content has on host

susceptibility. For history clearly indicates that any breeding improvement program that overlooks the natural breeding program of microorganisms and insects is courting disaster. As an example, in 1970 the southern corn leaf blight in the United States was an epidemic that resulted when susceptibility to this disease was inadvertently incorporated along with desirable characteristics in cultivars that were widely distributed. In one year this disease caused losses estimated to be near 15% of the national corn crop. Since disease and insects generally pose a greater threat to agricultural production in the tropics, it is imperative that any program designed to increase cassava yields through genetic improvement or altering cultural practices should also be designed to continually evaluate the changes in host susceptibility to disease and insects.

CHAPTER V

Biochemical Properties and Nutritive Value of Cassava[1]

ROOT

There are varying concentrations of carbohydrates, lipids, proteins, minerals, vitamins and water in cassava roots. Their composition is more or less similar to that of other tropical starchy roots (Table 5-1). An estimated average composition is 60-65% water, 30-35% carbohydrate, 0.2-0.6% ether extract, 1-2% crude protein, and a relatively low content of minerals and vitamins (Table 5-2). The variability which is evident in the results of approximate analyses can be attributed to strain or variety, location, a host of environmental conditions and the method of chemical analysis. This variation in composition can be illustrated by eight different samples analyzed by workers at INCAP (59). The figures in Table 5-3 show the minimum and maximum analyses in the eight samples. It is quite evident that some 3,000 different varieties would have an even wider range between the low and high values. The values reported would also depend on whether or not the tuber was peeled or dehydrated -- a detail which many authors generally ignore. Table 5-4 summarizes some of the data on proximate analyses from various sources on a dry weight basis. Table 5-5 snows the proximate analyses for unpeeled fresh cassava tuber and Table 5-6 presents the chemical composition of the peel or rind.

It would appear from a comparison of Tables 5-4, 5-5 and 5-6 that a considerable amount of protein is lost in the peel which is generally

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[1]Prepared by R. W. Seerley, University of Georgia, Athens, Georgia; D. J. Rogers, University of Colorado, Boulder, Colorado; and F. C. Obioha, Fort Valley State College, Fort Valley, Georgia.

TABLE 5-1. Average Food Composition of Five Starchy Roots, Per 100 Grams Edible Portion*

Item	Unit	Potatoes	Sweet potatoes	Fresh cassava	Yams	Taro
Food energy	calories	82	117	146	105	104
Water	gms	78	70	62.5	72.4	72.5
Carbohydrate	gms	18.9	27.3	34.7	24.1	24.2
Protein	gms	2.0	1.3	1.2	2.4	1.9
Fat	gms	0.1	0.4	0.3	0.2	0.2
Calcium	mgs	8	34	33	22	23
Iron	mgs	0.7	1.0	0.7	0.8	1.1
Vitamin A	I.U.	tr.	500[a]	tr.	tr.	tr.
Thiamine, B_1	mgs	0.10	0.10	0.06	0.09	0.15
Riboflavin, B_2	mgs	0.03	0.05	0.03	0.03	0.03
Niacin	mgs	1.4	0.6	0.6	0.5	0.9
Vitamin C	mgs	10[b]	23	36	10	5

*Data from FAO, Food Composition Tables for International Use (2d ed., Jan. 1953), pp. 23-24, and FAO, Food Composition Tables - Minerals and Vitamins for International Use (Mar. 1954), pp. 30-31. The abbreviation "I.U." indicates international units, "tr." indicates trace.

[a]Pale yellow variety: deep yellow average 7,000, nearly white 80 I.U.

[b]Approximate value at six-month's storage; at 0, 3, and 9 months after harvest the values are 40, 15, and 6 mgs, respectively.

Source: W. O. Jones (409), with permission from Stanford University Press

TABLE 5-2. Average Composition of Fresh Cassava Roots, and Estimated Daily Total Food Requirements of Adult Males.

Item	Unit	Composition of cassava roots per 1,000 grams edible portion				Adult male daily requirements	
		I[a]	II[b]	III[c]	IV[d]	U.S.A.[e]	Tropics[d]
Food energy	calories	1,310	1,460	1,310	1,440	3,200	2,500
Water	gms	600	625	647	620		
Carbohydrate	gms	320	347	327	350		
Protein	gms	7	12	11	7	65	65
Fat	gms	tr.	3	3	0		
Calcium	mgs	250	330	330	250	800	500
Phosphorus	mgs	...	...	530	500		
Iron	mgs	10	7	8	5	12	8
Vitamin A	I.U.	0	tr.	tr.	...	5,000	2,500
Thiamine, B_1	mgs	0.2	0.6	0.7	0.2	1.6	1.2
Riboflavin, B_2	mgs	1	0.3	0.3	0.7	1.6	1.2
Niacin	mgs	...	6	6	6	16	15
Vitamin C	mgs	300	360	400	300	75	25

[a]Data from B. S. Platt, Tables of Representative Values of Foods Commonly Used in Tropical Countries (Gr. Brit., Medical Research Council, Spec. Rep. Ser. 23, 1945), pp. 12-13.

[b]Data from FAO, Food Composition Tables for International Use (2d ed., Jan. 1953), p. 23, and FAO, Food Composition Tables - Minerals and Vitamins for International Use (Mar. 1954), p. 30.

[c]Data from U. S. Dept. Agr., Composition of Foods Used in Far Eastern Countries (Agr. Hdbk. #34, 1952), p. 20.

[d]Data from Lucius Nicholls, Tropical Nutrition (3rd ed., London, 1951), pp. 315, 406; requirements are for an active man.

[e]Data from U. S. National Research Council, Food and Nutr. Bd., Recommended Dietary Allowances (rev., 1953), p. 22; requirements are for an adult male, aged 25 years.

Source: W. O. Jones (409), with permission from Stanford University Press

TABLE 5-3. Average and Range in Composition of Cassava Roots.

	No. of analyses	Max.	Min.	Avg.
Dry matter, %	8	43.3	29.6	32.2
Nitrogen-free extract, %	8	90.9	85.3	88.9
Ether extract, %	8	1.1	0.6	0.9
Crude fiber, %	8	7.3	3.8	5.1
Crude protein, %	8	2.7	1.8	2.2
Ash, %	8	4.0	1.6	2.8
Calcium, mg/100 g	8	131.0	30.0	72.0
Phosphorus, mg/100 g	8	116.0	70.0	102.0
Iron, mg/100 g	8	70.1	13.7	33.8

Source: INCAP Publication No. E440 (59)

TABLE 5-4. The Composition of Peeled Cassava Tubers on Dry Matter Basis.

	Source		
	INCAP*	Chadha	Akinrele
Water (%)	66.0	62.5	71.50
NFE (%)	30.8	34.7	26.82
Ether extract (%)	0.27	0.3	0.13
Crude fiber (%)	1.36	1.3	0.12
Protein (%)	0.68	1.2	0.74
Mineral matter (%)	0.85	1.3	0.69
Calories/100 gm	127.5	146.0	----

*Institute de Nutricion de Centro America y Panama.

Source: I. A. Akinrele et al. (18); Y. R. Chadha (162); and INCAP (381)

TABLE 5-5. Chemical Composition of Unpeeled, Fresh Cassava Tubers.

	Source	
	INCAP	Ak ırele
Water (%)	67.8	68.06
Nitrogen-free extracts (%)	28.6	29.06
Crude fiber (%)	1.64	0.99
Crude protein (%)	0.71	0.87
Ether extract (%)	0.30	0.17
Ash (%)	0.90	0.85
Calories/100 gm	120.00	----

Source: I. A. Akinrele et al. (18) and INCAP (381)

TABLE 5-6. Chemical Composition of Cassava Peel (Rind).

	Wet basis	Dry basis
Dry matter (%)	27.3	----
NFE (%)	72.9	19.90
Ether extract (%)	2.2	0.60
Crude fiber (%)	14.6	3.98
Nitrogen (%)	0.8	0.22
Protein (%)	5.0	1.36
Ash (%)	5.1	1.39
Calories/100 gm	325.0	88.72

Source: INCAP (381)

removed during processing of the tubers for food. This contention is supported by Barrios and Bressani (91).

The composition of cassava as reported in the literature does not always indicate type, form or moisture basis on which the data were presented. The variation coming from these factors is enormous. Bitter cultivars differ from sweet cultivars, not only in the amount of HCN they contain, but also in the proportion of nutrients. Similarly, it makes the appraisal of nutrient value much easier if the data reported referred to the peeled root, unpeeled root, fresh or dry root, etc. Table 5-7 shows the chemical composition of various forms, and types of cassava roots, leaves and products as determined by Oyenuga (567).

It should be noted that only the peeled root is edible to humans whereas unpeeled cassava has been fed to various classes of livestock with varying degrees of success.

Maner (486) also reported a large variation in analyses of fifteen cultivars tested in Colombia (Table 5-8). The average composition of the fifteen varieties was 65% moisture, 1.25% crude protein, 1.45% crude fiber, 0.29% fat, 1.43% ash and 30.8% NFE, 0.12% calcium, 0.16% phosphorus, 0.06% sodium, 0.86% potassium and 0.37% magnesium.

Carbohydrates:

The bulk of the dried matter in cassava tubers consists of carbohydrates, 64-72% of which is reported to be starch; amylose and amylopectin together constitute 99% or more of the dry cassava starch (403). Recently, a new disaccharide - maniocose - was reported from cassava flour (387, 469). The most important other carbohydrate is sucrose, which can amount to as much as 17% in some sweet cultivars. Small

TABLE 5-7. Average Chemical Composition of Cassava on a Percent Dry Matter Basis.

	Dry matter %	Crude protein %	True prot. %	EE %	Crude fibre %	NFE %	Total ash %	Silica free ash %
Bitter cassava								
Root unpeeled	31.94	2.71	1.68	0.53	3.09	91.01	2.66	2.41
Root peeled	28.50	2.58	2.58	0.46	0.43	94.12	2.41	2.29
Peel only	27.94	5.29	4.59	1.18	20.97	66.63	5.93	4.60
Sweet cassava								
Unpeeled	31.94	2.38	1.30	0.65	1.95	92.13	2.89	2.73
Peel only	28.50	1.66	1.66	0.65	1.60	90.86	5.23	4.96
Sweet cassava	27.94	5.61	2.37	1.39	10.31	78.25	4.44	3.83
Cassava leaves	25.60	14.69	13.76	8.39	15.63	45.22	16.07	7.87
Gari	86.47	1.20	1.02	0.38	2.31	94.03	2.08	0.92

Source: V. A. Oyenuga (567)

TABLE 5-8. Proximate Analysis of 15 Colombian Cassava Varieties[1].

Variety	Moisture	Protein	Fiber	Fat	Ash	Nitrogen-free extract
	%	%	%	%	%	%
Llanera	67.90	2.33	0.97	0.18	0.95	27.67
Santa Catalina	64.76	2.14	1.16	0.24	1.00	30.71
H-50	66.71	0.56	2.03	0.35	1.71	28.58
Tolima	61.85	0.4[illegible]	1.35	0.25	1.54	34.61
C.M.C.-50	60.61	1.55	1.09	0.36	1.40	35.07
I-35 Brava	61.21	2.06	1.18	0.31	1.03	34.14
Blanca No. 2	62.70	1.25	1.02	0.29	1.36	33.36
C.M.C.-1	62.18	1.97	2.16	0.30	2.49	30.89
C.M.C-3	61.50	1.70	1.77	0.24	1.38	33.34
C.M.C.-4	67.59	1.71	3.46	0.35	1.59	25.27
Seis Meses Comun	65.35	0.67	1.00	0.43	1.29	31.35
Amarilla	64.16	0.59	1.64	0.33	1.81	35.90
Tempranita	77.32	0.63	1.07	0.24	1.58	19.17
La Respetada	62.84	1.03	1.02	0.22	1.36	33.49
Bartolita	68.81	0.18	0.77	0.25	0.94	29.05
Average	65.03	1.25	1.45	0.29	1.43	30.84

[1]Nutrition Laboratory - ICA.

Source: J. H. Maner (486)

quantities of fructose (levulose) and dextrose are also reported, but these could have been formed by the action of enzymes on the sucrose.

The rate of starch deposition in cassava roots during the growth cycle of the plant was studied by Cours (201). Typically the starch content reaches an early maximum near the end of the first year, and then it may decline until production of starch is resumed again. The peaks coincided with periods when the leaf cover was a minimum. Viswanathan et al. (804) observed diurnal variations in some enzymes of carbohydrate metabolism in cassava leaves, indicating carbohydrate synthesis in the daytime and breakdown in the night. The metabolic activity of starch granules from cassava plants was investigated by Viswanathan and Krishnan (800, 801, 802, 803). Indira and Sinha (382) concluded that though the tuber development was affected by different durations of illuminations, the starch deposition was not influenced.

Cassava starch granules vary from 5 to 35μ (average 17μ). Magoon and Appan (473) have reviewed some of the properties of cassava starch. Cassava starch gelatinizes almost completely and forms a colorless, odorless and transparent soft gel when set. The gelatinizing temperature of cassava starch was 71°C. The gel was relatively stable and retrogradation did not occur. The swelling and solubility patterns of cassava starch were reported by Rasper (618, 619). Commercial samples of cassava starch contain 9-18% moisture, 0.3-1.0% protein, 0.1-0.4% fat, 0.1-0.8% ash and 81-89% of starch, fibre, etc. (162). Kaufman (417) describes tests of quality of commercial cassava starch.

There are indications that the glucoside content of the tuber is correlated with the starch content, because bitter cultivars are usually

high starch yielders. There is also some relationship between starch content and palatability of the tuber. Doku (239) indicated that tubers with higher starch content had lesser fibre content and therefore, were less "stringy". Others have suggested that when the parenchymatous cells were packed with starch grains, they readily burst open on cooking, thus giving the cooked product good palatability. Magoon (471) and Magoon et al. (474) reported the selection of high starch yielding strains, with 29-31% starch on fresh weight basis in contrast to 20-25% of the native strains. Vasudevan et al. (778) isolated a radiation induced mutant yielding 31.3% starch on a fresh weight basis.

Lipids:

The level of lipids is quite low in cassava and there could be a possibility of a deficiency in certain animal diets. Cassava has only approximately 0.5% ether extractable material, while most animals should have 1 to 2% lipids in their diets. The type of fatty acids in cassava is not generally known.

Protein and Amino Acid Profile:

Cassava roots have a low content of nitrogenous substances varying from 0.7-2.6% (403) and a major portion of the total nitrogen exists as simple nitrogenous compounds (703). Cassava proteins are comparable to rice protein in digestibility; the biological value (Block and Mitchell equivalent) of the total proteins is 48%.

The crude protein content of roots appears to be relatively stable and constant with maturity of the plant. Research at ICA in Colombia showed that roots harvested at 12 to 17 months of age had similar crude protein content (486).

The peeling contains a higher percent of nitrogen than the flesh portion of the root, yet the flesh contains more total nitrogen by virtue of the wide flesh:peel volume ratio.

Table 5-9 shows that roots and tubers compare unfavorably with cereal grains and especially legumes in amino acid content. Lysine, methionine and tryptophan are especially low. A high yielding variety (Llanera) has been discovered at the ICA Experimental Station at Cali, Colombia. The yield was 78 tons per hectare in one experimental plot (486). Equally exceptional about this variety is that the crude protein content is much higher than the average of many varieties. It contained 2.32% crude protein on a wet basis or 7.25% on a dry matter basis. If varieties can be developed with more amino acids, it would enhance the value of cassava as a food and/or feed.

The amino acid analyses of two varieties of cassava are compared in Table 5-10 with that of Colombian hybrid corn H-253 and a Colombian opaque-2 corn, H-255. The lysine content of the cassava varieties appears to be more favorable in these varieties, but methionine was very low.

According to Close et al. (184), the protein of tapioca meal includes the following amino acids: 4.4% aspartic acid, 2.1% threonine, 1.9% serine, 12.7% glutamic acid, 1.6% proline, 2.4% glycine, 4.6% alanine, 2.6% valine, 0.6% cystine, 1.0% methionine, 2.0% isoleucine, 2.9% leucine, 1.6% tyrosine, 2.3% phenylanine, 3.5% lysine, 0.6% tryptophan, 10.4% ornithine, 1.2% histidine and 3.7% arginine. Sreeramamurthy (703) also reported that the essential amino acids present in the total proteins (1.33% in the sample) are (g/16 gN):

TABLE 5-9. Amino Acid Content Per 100 Grams Food.

Food	Moisture (grams)	Nitrogen (grams)	Conversion factor (W)	Protein (gram)	Lysine (mg)	Methi-onine (mg)	Threo-nine (mg)	Trypto-phan (mg)	Total essential amino acids (mg)	Total amino acids (mg)
Cereal grains										
Barley	12	1.88	5.83	11.0	406	196	389	180	4,203	11,118
Maize	12	1.52	6.25	9.5	254	182	342	67	3,820	9,262
Millet	11	1.55	6.25	9.7	332	239	374	189	3,979	9,505
Oats	10	2.23	5.83	13.0	517	234	462	176	5,169	12,998
Rice-brown	13	1.26	5.95	7.5	299	183	307	98	3,033	7,973
-polished	13	1.13	5.95	6.7	255	150	234	95	2,695	6,785
Rye	12	1.89	5.83	11.0	401	172	395	87	3,732	10,868
Sorghum	11	1.62	6.25	10.1	204	141	306	123	3,945	9,756
Wheat	12	2.09	5.83	12.2	374	196	382	142	4,280	12,607
Roots and tubers										
Potato	78	0.32	6.25	2.0	96	26	75	33	667	1,572
Sweet potatoes	70	0.21	6.25	1.3	45	22	50	22	414	994
Taro (Colocasia)	72.5	0.29	6.25	1.8	70	24	74	26	707	1,737
Yam (Dioscoria)	72.4	0.38	6.25	2.4	97	38	86	30	821	2,009
Cassava (Manihot) meal	13.1	0.26	6.25	1.6	67	22	43	19	404	1,184
Legumes (pulses)										
Beans (Phaseolus)	11	3.54	6.25	22.1	1,593	234	878	223	8,457	20,043
Beans, Broad (Vicia)	11	3.74	6.25	23.4	1,513	172	786	202	8,244	20,951
Chick-pea	11	3.22	6.25	20.1	1,376	209	756	174	7,802	19,290
Cowpeas (Vigna)	11	3.74	6.25	23.4	1,599	273	842	254	8,640	21,086

TABLE 5-9. (continued)

Food	Moisture (grams)	Nitrogen (grams)	Conversion factor (W)	Protein (gram)	Lysine (mg	Methi-onine (mg)	Threo-nine (mg)	Trypto-phan (mg)	Total essential amino acids (mg)	Total amino acids (mg)
Legumes (continued)										
Peanut	5.2	4.69	5.46	25.6	1,036	338	764	305	9,502	27,610
Lentil	11	3.87	6.25	24.2	1,739	194	960	231	9,504	23,447
Peas	11	3.60	6.25	22.5	1,692	205	914	202	8,464	20,901
Pigeon pea	11	3.34	6.25	20.9	1,607	107	608	117	7,505	18,460
Soybean	8	6.65	5.71	38.0	2,653	525	1,603	532	16,339	40,945
Meat and poultry										
Beef and veal	61	2.83	6.25	17.7	1,573	478	812	198	7,875	17,163
Chicken	66	3.20	6.25	20.0	1,570	502	794	205	8,380	18,206
Pork	42	1.90	6.25	11.9	961	321	583	162	5,203	11,496
Egg (hen)	74	1.98	6.25	12.4	863	416	634	184	6,338	12,763
Fish, fresh, all types	74.1	3.01	6.25	18.8	1,713	539	861	211	8,465	18,338
Fish, meal	10.1	12.00	6.25	75.0	5,808	2,052	3,180	720	30,360	70,308
Milk, cows	87.3	0.55	6.38	3.5	268	86	153	48	1,620	3,553

Source: FAO, Amino Acid Content of Foods and Biological Data on Proteins. Nutritional Studies No. 24, Rome 1970 (296)

TABLE 5-10. Amino Acid Values of Cassava and Corn Varieties.

Amino Acid[1]	Variety			
	Cassava[2] C.M.C.-4	Cassava[2] Llanera	Common[3] Corn H-253	Opaque-2[3] Corn H-255
Arginine	16.0	18.0	4.6	6.2
Histidine	0.5	2.3	2.9	2.7
Isoleucine	2.9	1.7	5.0	3.6
Leucine	3.2	2.0	16.0	8.0
Lysine	3.2	2.6	2.8	4.0
Methionine	Trace	Trace	3.0	4.5
Alanine	1.1	2.6	9.4	5.9
Threonine	6.8	6.2	3.5	3.3
Phenylalanine	1.5	1.0	5.4	3.8
Valine	2.1	1.1	7.2	5.6
Tyrosine	1.0	0.6	4.9	3.5
Glycine	1.4	0.9	4.1	5.3
Glutamic acid	9.8	5.3	20.6	15.2

[1]Expressed as percentage of protein or grams of amino acid per 100 grams of protein.

[2]Metabolic Laboratory - University of Valle Hospital; Cali, Colombia.

[3]Shuman Chemical Laboratory, Inc., Battle Ground, Indiana.

Source: J. H. Maner (486)

arginine 7.74, histidine 1.50, isoleucine 5.33, leucine 5.56, lysine 6.23, methionine 0.60, phenylalanine 3.45, threonine 3.83, tryptophane 0.53, and valine 4.51. Methionine and tryptophane are deficient; some workers have reported the complete absence of the former. The essential amino acid profile of cassava based diet in Indonesia, as reported by Bailey (78), also indicates that it is particularly deficient in sulphur containing amino acids (methionine, cystine and cysteine). Osuntokun et al. (564) pointed out that both cysteine and cystine are involved in the cyanide detoxication (cyanide is produced when a cyanogenic glucoside (linamarin) present in the dietary derivative of cassava is hydrolysed by linase or by acid. This cyanide is mainly detoxicated by conversion to thiocyanate, in the process of which it reacts with cysteine and cystine), and excessive cyanide detoxication may be responsible for the low concentration of sulphur containing amino acids. The findings of Adriaens (11) that nitrogenous fraction of cassava flour varied widely according to the method of preparation of the flour would also indicate that the degree of detoxication of the cyanide would significantly affect the quantity and quality of cassava protein. Soaking the roots transforms, under some circumstances, the arginine into ornithine, an amino acid hitherto unknown in the higher vegetables, although known to be present in mushrooms (11). At the same time, some of the nitrogen formerly held in certain amino acids (arginine, tyrosine, tryptophane) is released as free ammonia. The investigations of Adriaens and associates (9, 10, 11, 12, 13, 103, 104) indicated that the amount and quality of protein in cassava roots may be altered significantly by processing; they also suggested that this has

implications for specific nutritional problems of Africa, including Kwashiorkor. However, Jones (409) stated that the incidence of Kwashiorkor is by no means well correlated with cassava comsumption, appearing rather to be a function of total protein intake, and that the connection suggested by Adriaens and associates must remain unproved until much more is known about Kwashiorkor and cassava protein. Bailey (78), investigating the nutritional problems in the cassava areas of Indonesia, also concluded that it cannot be indisputably stated that the sulphur containing amino acid levels in the cassava diets are too low. Cox et al. (205) established that in human beings supplementary methionine failed to increase nitrogen retention. Johnson et al. (402) also proved that methionine supplements did not save body protein or decrease the nitrogen losses in humans subsisting on low protein diets. However, Bailey (78) did not rule out the possibility of any connection between cassava diet and Kwashiorkor because Ladell and Phillips (438) found that the nitrogen retention in Africans on diets of cassava and peanut flour increased when methionine was added to the diet.

All these findings will have to be taken with caution because, in the light of our modern knowledge of human metabolism, it is recognized that protein absorption and utilization in the human system is an extremely complex phenomenon.

Efforts have been made in the past to increase the protein content of cassava roots by interspecific hydridization with M. saxicola and M. melanobasis. Over a period of years, beginning in 1932 and ending with the Japanese occupation of Java in 1942, Bolhuis carried on a program of cassava breeding for increased protein content in roots. Crosses with

M. saxicola yielded a few seedlings with as much as 2% protein in the fresh roots, but in the clones propagated from these seedlings protein content fell back to typical levels (118). Lanjouw (441) has determined that fresh roots of M. saxicola posses 2.3% albumen. Jennings (393) reported that the roots of the F_1 progeny of M. esculenta x M. melanobasis possessed approximately twice as much protein as their cassava parent. Ammann (31) reported that some Indochinese cassava cultivars contained as much as 7.4% nitrogenous material on a dry weight basis. A number of crosses were made using these cultivars but the work was interrupted by the Japanese occupation. Barrios and Bressani (91) reported 6.5% protein in a Panamanian cultivar. Recently, a similar report of a cultivar in Colombia, "Llanera", with as much as 7.25% nitrogenous matter in the roots generated much excitement. Estimates of total nitrogenous matter will have to be viewed with caution because it is not certain whether the breakdown products of cyanogenic glucosides do enhance the total nitrogen content or not. Nartey (532) showed that the hydrolytic products of glucosides are incorporated into amino acids for protein synthesis in cassava. Therefore, it is not unlikely that the reported cultivars of high nitrogenous content turn out to be nothing but bitter cultivars with high glucoside content. Besides, the entire tuber including the rind is sometimes ground up for nitrogen estimates, in which case the values can be abnormally high since most of the glucosides of the tuber are concentrated in the rind. Jennings (398) stated that the protein in cassava roots tends to be concentrated in the outer zones of the root. It is not clear whether Jennings meant the phelloderm (the rind) or outer zones of the xylem parenchyma.

A discovery of great potential significance is the protein enrichment of cassava substrate through microbial fermentation. Gray and Abou-El-Seoud (346), and the work reported from the Tropical Products Institute, London (Confidential), indicate that it is possible to increase the protein content of cassava by a factor of 6-8. Fermenting cassava roots is the standard centuries-old method of processing cassava roots for human consumption in many parts of South America and Africa, but no accurate estimates of the chemical composition of the fermented products are available. This is particularly significant because, besides making the product rich in total protein, microbial activity can also possibly modify the amino acid profile, making the protein more balanced. McPherson (496) indicated that essential amino acids, such as methionine, can be supplemented in the diet through microbial fermentation, and in this context the possibility of increase in the amounts of sulphur containing amino acids including methionine (known to be deficient in fresh roots of cassava) in the fermented cassava products, needs to be investigated.

Minerals and Vitamins:

Cassava roots are relatively rich in calcium and ascorbic acid and contain nutritionally significant amounts of thiamine, riboflavin, and niacin. Jones (409) estimates that 1 kilo of fresh cassava roots could contribute 66% calcium, 125% iron, 58% thiamine, 83% riboflavin, 40% niacin and 1600% vitamin C of the daily requirements of an active adult living in the tropics, but he also points out that in the process of soaking, grating, washing, heating, pounding, etc. (methods employed in processing cassava roots for human consumption) a large amount of the

vitamin and mineral content was lost. Estimates of vitamin and mineral content of some cassava products are presented in Tables 5-11, 5-12 and 5-13.

Data from Chadha (162) indicates the following values for fresh, wet, peeled tuber: calcium - 33 mg/100 g; iron - .07 mg/100 g. Vitamin C appears the most unstable and may be entirely eliminated (621), but when peeled roots were boiled only half of the vitamin C was lost. Roots roasted with the peel on lost only a small amount of the ascorbic acid. Most of the vitamin B_2 may also be lost in washing and steeping, but vitamin B_1 seems to be more persistent (520, 521, 522, 523, 556, 635).

LEAVES

Cassava leaves are rich in protein; the percentage of crude protein of some Jamaican cultivars ranged from 20.6 to 36.4 on dry weight basis. The 4 different estimates of the composition of fresh cassava leaves as compiled by Jones (409) is presented in Table 5-14. Seventy-five percent of the crude protein is reported to be true protein and its feeding value is high (779).

The summary of proximate analysis and the amino acid profile of Brazilian and Jamaican cassava leaf meal samples reported by Rogers and Milner (652) is shown in Tables 5-15 and 5-16. The cassava leaf protein was deficient in methionine and possibly marginal in tryptophan only. The values of all other essential amino acids exceed the requirement of the FAO reference pattern. The lysine level is remarkably high. Rogers and Milner (652) considered cassava leaf protein as superior as soy bean protein. Rat feeding tests indicated that supplementation of

TABLE 5-11. Mineral Composition of Dry Cassava Root.

	With peel	Without peel	Peel only
Calcium (mg/100 g)	72.0	64.0	313.0
Phosphorus (mg/100 g)	102.0	97.0	111.0
Iron (mg/100 g)	33.8	45.6	90.4

Source: Y. R. Chadha (162)

TABLE 5-12. Vitamin Content of Cassava.

	Fresh, peeled	Dry, peeled
Thiamin (mg/100 g)	0.06	0.07
Riboflavin (mg/100 g)	0.03	0.03
Niacin (mg/100 g)	0.60	0.70
Carotene (mg/100 g)	trace	0.012
Ascorbic acid (mg/100 g)	36.00	---

Source: Y. R. Chadha (162) and INCAP (381)

TABLE 5-13. Estimates of Vitamin and Mineral Content of Some Cassava Products.

(Milligrams per 100 grams product)

Product	Source	Vitamin B_1	Vitamin B_2	Niacin	Vitamin C	Calcium
Farinha de mandioca	a	.107-.165	.044-.07	2.3	...	...
Farinha de mandioca	a	.020	.010	1.7	...	...
Gari, white	b	...	...	...	...	44
Gari, white	b	...	...	...	...	46
Gari, yellow	b	...	...	...	...	83
Farinha de raspas	a	...	...	1.8	...	...
Flour and meals	c	...	...	...	...	20-60
Flour	g	...	...	...	1.4-1.7	...
Roots, dried after soaking	d	...	—	0.8	—	86-100
Cassava cakes	e	.06	.10	...	...	...
Chickwangue, batons	f	...	...	...	2.0	...
Cooked roots	a	.109-.218	...	...	...	...
Boiled roots	g	...	...	...	20,33	...
Roasted roots	g	...	...	...	26,47	...

Sources as follows:

[a]F. A. de Moura Campos, "Estudo de algunas tubérculos usados na alimentacão Brasileira," in Problemas brasileiros de alimentacão (Serv. de Aliment. da Previd. Social. Biblio. Bras. de Nutr.), Sao Paulo, 1949, pp. 763-768.

[b]J. Périssé and S. Le Berre, Table de composition des aliments du Togo apercu sur l'alimentation des populations rurales (Inst. de Rech. du Togo, n.d.), p. 12.

[c]J. L. Bergouniou, A. O. F. Problème alimentaire et nutritionnel (Gouv. Gen. de l'Afrique Occidentale Francaise, 1951), pp. 20, 21; O. Guernelli, "Estudo sôbre as possibilidades de enriquecimento da farinha de mandioca," Trabalhos e Pesquisas (Inst. de Nutr., Univ. do Brasil, 1952); and Barros Barreto and Tito Cavalcanti, "Problemsa Alimentar da Amazonia," Memórias do Inst. O. Cruz, Tomo 45, Fasc. IV, 1947, Arquivos Bras. de Nutr. (Tomo 6, Num. 2, Inst. de Nutr., Univ. do Brasil, 1949).

[d]G. M. Culwick, A Dietary Survey Among the Zande of the South-Western Sudan (Sudan, Min. Agr., 1950), p. 139.

[e]J. M. Bengoa and W. Jaffé, Tabla de Composicíon de Alimentos, Serie de Pub. del. Inst. Nac. de Nutr. (rev. ed., Caracas, 1950), p. 8.

[f]B. Bergeret, "Teneur en acide ascorbique de quelques aliments du Sud-Cameroun," Médecine Tropicale, Mar.-Apr. 1957.

[g]W. D. Raymond, W. Jojo, and Z. Nicodemus, "The Nutritive Value of Some Tanganyika Foods: II-Cassava," E. Agr. Agr. J. (Nairobi), Jan. 1941, pp. 156-1

Source: W. O. Jones (409), with permission from Stanford University Press

TABLE 5-14. Composition of Fresh Cassava Leaves.

(Per 100 grams edible portion)

Item	Unit	I	II	III	IV	V
Food energy	calories	44	62	55	...	...
Water	gms	85	80.5	74	...	...
Carbohydrates	gms	6	9.6	5	...	...
Protein	gms	4	6.8	7.5	...	...
Fat	gms	0.4	1.3	0.7	...	...
Calcium	mgs	210	206	100	206	...
Iron	mgs	3	2.0	3.0	3.5	...
Vitamin A	I.U.	13,000[a]	10,000[b]	9,000	...	...
Thiamine, B_1	mgs	0.15	0.16	0.30	0.15	0.27
Riboflavin, B_2	mgs	0.25	0.30	0.43	0.30	0.42
Niacin	mgs	0.85	1.8	1.5	2.0	3.53
Vitamin C	mgs	100	265	60[c]	311	320

Sources as follows:

I. Data from B. S. Platt, Tables of Representative Values of Foods Commonly Used in Tropical Countries (Gr. Brit., Medical Research Council, Spec. Rep. Ser., 253, 1945), pp. 20-21.

II. Data from FAO, Food Composition Tables - Minerals and Vitamins for International Use (Mar. 1954), pp. 35, 48.

III. Data from G. M. Culwick, A Dietary Survey Among the Zande of the Southwestern Sudan (Sudan, Min. Agr., 1950), p. 141.

IV. Data from R. S. Harris and Hazel E. Munsell, "Edible Plants of Central America," J. of Home Economics, Oct. 1950, p. 630.

V. Data from F. A. de Moura Campos, "O Complexo da mandioca como traco da influência amerindia na alimentacão brasileira," O Hospital (Rio de Janeiro), June 1951.

[a]As carotene.

[b]Young green leaves; shoots, green color not yet developed, about 110 I.U.

[c]As eaten.

Source: W. O. Jones (409), with permission from Stanford University Press

TABLE 5-15. Summary of Proximate Analysis of Cassava Leaf Meal.

	Jamaican samples (Nos. 312-321)				Brazilian samples (Nos. 322-331)			
	Frozen (fresh)		Dried[1]		Frozen (fresh)		Dried[1]	
	Range	Average	Range	Average	Range	Average	Range	Average
Moisture (%)	76.72-80.50	79.2			67.01- 74.82	71.2		
Protein (N x 6.25)(%)	3.73- 6.54	5.4	18.52- 32.42	25.8	5.37- 10.74	7.8	17.80- 34.82	27.3
Ether extract[2] (%)	.77- 2.67	1.6	3.95- 12.78	7.6	1.91- 4.18	3.0	6.64- 15.24	10.5
Ash (%)	1.47- 2.23	1.8	7.46- 11.07	8.8	1.40- 2.01	1.6	4.65- 6.83	5.7
Crude fiber (%)	1.34- 1.92	1.7	6.41- 9.43	7.9	1.11- 1.78	1.4	3.98- 6.79	4.8
Carbohydrates[3] (%)	8.17-13.77	10.4	40.51- 59.15	50.1	12.28- 19.76	14.5	40.96- 63.74	51.9
Calories (per 100 g)	70.04-86.70	77.4	347.80-404.00	372.5	101.50-134.40	118.0	387.20-438.70	411.0
Cyanide (ppm, wet)	33.00-73.00	46.0			42.00- 80.00	56.5		

[1]Dry values calculated from analyses of fresh frozen material.

[2]Considered as fat for the calculation of calorie values.

[3]Calculated by difference.

Source: D. J. Rogers and M. Milner (652)

TABLE 5-16. Amino Acid Profiles for Cassava Leaf Protein (Percent, 16 g Nitrogen Basis).

Amino acid	Average for Jamaican samples	Range of variation %	Average for Brazilian samples	Range of variation %	FAO essential amino acid reference pattern
Alanine	5.98	5.66- 6.39	6.19	5.22- 6.66	---
Arginine	5.28	4.00- 6.80	6.12	5.30- 7.35	---
Aspartic acid	10.14	9.49-10.72	9.63	9.10-10.53	---
Cystine	1.37	1.04- 1.99	1.04	0.74- 1.47	---
Glutamic acid	10.22	9.37-11.83	10.12	8.80-11.02	---
Glycine	5.39	4.29- 5.95	5.32	4.94- 5.58	---
Histidine	2.23	1.44- 3.28	2.56	1.48- 3.40	---
Isoleucine	5.01	4.85- 5.26	4.84	4.34- 6.31	4.2
Leucine	8.89	7.66- 9.67	8.85	8.33- 9.47	4.8
Lysine	7.20	6.00- 8.24	6.33	5.60- 7.82	4.2
Methionine	1.65	1.39- 1.84	1.71	1.51- 2.00	2.2
Phenylalanine	5.82	5.06- 6.39	5.53	5.11- 6.65	2.8
Proline	4.64	4.12- 6.14	5.40	5.12- 6.40	---
Serine	5.16	4.74- 5.81	4.60	3.58- 5.56	---
Threonine	4.92	4.70- 5.14	4.73	4.49- 5.08	2.8
Tryptophan	1.47	1.28- 1.69	2.07	1.56- 2.50	1.4
Tyrosine	4.18	3.74- 4.82	3.93	3.71- 4.08	---
Valine	5.73	5.30- 6.22	5.58	5.34- 6.09	4.2

Source: D. J. Rogers and M. Milner (652)

0.3% methionine to a diet containing dried cassava leaf meal yielded results that compared well with casein (584, 585, 586, 587). Singh (683) discussed possibilities of extracting protein from cassava leaves, for use as food supplement. In Costa Rica dehydrated leaf meal produced in a food dehydration plant contained 22-25% protein (403).

Fresh cassava leaves contain appreciable quantities of ascorbic acid (621), but once picked they lose it fairly rapidly at tropical temperatures. Raymond et al. (621) reported that fresh leaves from the plantations in Tanzania had 352.2 mg/100 g of ascorbic acid. He also extracted the juice from cooked leaves and vacuum concentrated it and obtained preparations containing upwards of 2,000 mg ascorbic acid per 100 g. Leaves also contained carotene, 9,746-11,136 u/100 g in the fresh leaves and 7,172 u/100 g after cooking. Van Veen (779) showed by chromatographic analysis that vitamin A, vitamin B_1 and vitamin B_2 were also present in addition to ascorbic acid.

CYANOGENIC GLUCOSIDES

Cassava cultivars contain varying quantities of cyanogenic glucosides. Besides the toxicity, the cyanogenic glucosides are of significance in that they are linked by chemical pathways with proteins. Nartey (532) points out that the hydrolytic products of glucosides are made available, in cassava plants, for incorporation into amino acids for protein synthesis.

Cassava plants possess two cyanogenic glucosides; linamarin and lotaustralin (105, 181, 258). The former accounts for 93% of the total cyanogenic glucosides and the latter 7% (532). These glucosides break down after the plant is harvested into prussic acid (hydrocyanic acid

or HCN), acetone and glucose, through the action of enzymes or organic acids; thus the hydrocyanic acid is liberated and the product becomes detoxicated. The various ways of processing cassava roots for consumption, practiced by cassava eaters all over the world, include procedures for accelerating the detoxication. Heating, soaking the roots in water, cutting or grating roots, etc., accelerate the activity of the hydrolytic enzyme system present in the roots, thus hydrolizing the glucosides. Another enzyme system present in the roots catalyzes the condensation of hydrocyanic acid with aldehyde compounds, thus the prussic acid is eliminated (403). The glucosides are also highly soluble in water and decompose when heated to a temperature of 150°C. Fermentation of roots results in the production of organic acids which hydrolize the glucosides liberating gaseous HCN (16, 18, 188). Unhydrolyzed glucosides, if remaining in ingested food, can still be broken down by enzymes that may already be present in the intestinal tract (409).

Cassava cultivars are usually called "sweet" or "bitter" by farmers. Whether these differences are based strictly on taste or upon the content of CN^- is a question that has not been settled. Pereira and Pinto (593) and Pereira et al. (591) have concluded that CN^- content is the sole basis for the divisions, but Sinha and Nair (685) indicate that other factors, possibly sugars in the roots, influence organoleptic evaluations.

The content of HCN in the peeled tuber of samples analyzed by various workers ranged from 6-190 mg/kg (838); 30-370 mg/kg (347); 29-213 mg/kg (569); and 31-151 mg/kg (117). Analysis of about 100 cultivars for available HCN by Raymond et al. (621) gave an average

value of 158 milligrams from one kilogram of whole root, with a maximum value of 434 milligrams. Bolhuis (119) classifies roots containing less than 50 milligrams of prussic acid per kilogram of flesh as non-toxic (or sweet), on the basis that the minimum lethal dose of prussic acid for human beings is 50-60 milligrams.

Prussic acid content varies markedly with growing conditions, soil, moisture, temperature, perhaps altitude, and with age of the plant (409). Considerable research is needed to determine the precise mechanisms influencing the concentration of CN^-, both during the ontogeny of the root and under different environmental conditions. In general, prussic acid content tends to be higher as growing conditions are less favorable (409). Bolhuis (119) states that potassium deficiency clearly leads to increased toxicity. Sinha and Nair (684) studied the influence of various sources of nitrogen (nitrate, nitrite, ammonium sulphate, ammonium nitrate, urea and glycine) on the cyanogenic glucoside content in cassava leaves and young roots in sand culture and concluded that in the initial stages glycine and ammonium sulphate enhanced the amount of cyanide. After five weeks of growth, urea and ammonium nitrate produced less amounts of cyanoglucosides. They also found that certain amino acids in the soil such as valine, isoleucine and glycine, enhanced cyanoglucoside content 3 to 4 fold within 24 hours. It is known that valine and isoleucine act as precursors in the synthesis of linamarin and lotaustralin, respectively (532). There is some evidence that low temperatures increase the prussic acid content of roots (161). There is also considerable variation with respect to the distribution of glucosides within the root tissues, usually with higher

concentrations in the phelloderm (rind) and along the central vascular core of the root. Wood (838) reported that the mean value of HCN for the phelloderm was over 10 times that of the mean value of HCN for the remainder of the tuber, in the samples analyzed. Rogers (643) indicated that "sweet" varieties tend to have most of their tuber glucosides concentrated in the phelloderm, whereas "bitter" varieties may have a more even distribution throughout the parenchymatous storage tissues. Pereira et al. (590) observed that the age of the roots is not statistically correlated with the prussic acid content in the roots. Wood (839) also concluded that the glucoside concentration in the root was not affected by its age, however, the enzyme concentration became low as the roots approached maturity, thus affecting the readiness with which hydrogen cyanide was released when the roots were cut.

It has been suggested (838, 839) that the function of the glucosides in cassava is that of liberating hydrogen cyanide and thereby repelling insect pests when they attack the plant. Nartey (532) suggests that the glucosides are active rather than inert constituents of the plants. He adds that during germination high concentrations of valine and isoleucine are made available by the action of proteinases and peptidases on reserve proteins, and under non-photosynthetic conditions in the dark it is highly probable that these amino acids are catabolized through energy yielding processes which lead to the formation and accumulation of high concentrations of the glucosides. The occurrence of highly active linamarase in cassava seedlings provides the condition under which the glucosides may subsequently be hydrolyzed and the hydrolytic products made available for respiratory breakdown or incorporation into amino acids for protein synthesis.

Cassava leaves have been reported to contain varying amounts of prussic acid, 200 mg/kg of fresh leaves (779), 180-200 mg/kg (621). Raymond et al. (621) and Razafimahery (622) indicate that the leaves contain comparatively lesser quantities of prussic acid than in roots. Pechnik and Guimaraes (584) analyzed the prussic acid content of cassava leaf meal and reported that the rate of detoxication in leaves was slower than that of roots.

Some investigators have considered the possibility of cumulative or chronic poisoning due to prussic acid and have suggested that the prussic acid of cassava is responsible for a number of illnesses, including poliomyelities (667), sterility (666), and various pellagroid diseases (182). Osuntokun et al. (564), assessing the plasma amino acid levels in patients with tropical atoxic neuropathy in Nigeria, observed that the plasma thiocyanate concentration was high. He attributed this to excessive cyanide detoxication, in the process of which the sulphur containing amino acids react with the cyanide and get depleted. Ekpechi et al. (274) reported that cassava diets in Nigeria, particularly those involving unfermented cassava which may not be completely devoid of prussic acid, is goitrogenic. Recent investigations in the State of Kerala (India), where large amounts of cassava are consumed as secondary staple, show the prevalence of a kind of diabetes called K-diabetes (personal communications from Dr. S. Paranjothi). It is suspected that this may be due to prussic acid.

Vogt (805), investigating the use of tapioca meal in poultry rations, indicated that the residual prussic acid in the tapioca meal causes growth depression.

CHAPTER VI

Utilization of Cassava as a Human Food[1]

Cassava is utilized as human food, in one form or another, in all five continents. The extent to which it is used varies from daily (staple) consumption in those tropical countries where it is widely grown, to occasional dessert items in western and European countries in which it is prepared in a form widely known as tapioca.

Reliable data on actual consumption in most countries are difficult to obtain, since cassava is largely produced by subsistance farmers and maintains a more or less backyard status in the overall economic and industrial framework of these countries. Furthermore, in most countries where cassava is widely grown, up-to-date statistics on food commodity movement and trends are not maintained.

Gross national production figures are generally available, but export/import data are too fragmental to permit a valid estimate of consumption to be calculated. The most realistic estimates must therefore be developed from indirect sources, such as total hectares devoted to the crop, total gross production computed on per capita basis, gross caloric yields, proportion of national food expenditures pertaining to cassava products and finally, recorded import or export data. Within any given country, these sources are generally reliable, but a considerable margin of error must be allowed if global estimates of consumption are desired.

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CALORIC PRODUCTION AND CONSUMPTION

Selected Countries:

Yield data on cassava varies immensely between countries, between localities within a country and between varieties within a locality. It is therefore impossible to extrapolate total global production from available statistics on hectares under cassava. Yet another variable in the estimation of yield is the moisture content. Several authors are content with expression of total yields without any reference to moisture content or total dry matter yields. The total caloric yield of cassava grown in Nigeria in 1950 was 42,188,563 millions (570). Assuming the population of Nigeria in 1950 to be 55 million and taking 2,600 calories as the average per capita daily caloric requirement, it can be calculated that cassava alone was able to supply 2,100 calories per capita per day. In other words, the entire population of Nigeria could have relied on cassava alone to meet 80% of its caloric needs (Table 6-1).

In 1966, the Dominican Republic produced about 150,000 metric tons of cassava. With its population of 3.5 million, this country can be said to have consumed on the average, 119 grams of cassava, per capita, per day. The caloric equivalent of this figure is 457, which represents almost 18% of the daily caloric requirements for the entire population (Table 6-1). It should be noted that these are apparent consumption figures since import and export data are fragmental.

This estimate is quite realistic and has tempted many nutritionists to conclude that diets of tropical peoples have an overwhelming preponderance of starch. Actual consumption may not be close to this estimate

TABLE 6-1. Calorie Yields and Consumption from Cassava.

Country	Year	Population (millions)	Calorie yield (millions)	Per capita consumption cal/head/day	Percent of calorie requirement
Nigeria	1950-51	55	42,188,563	2,101.5	80
Ghana	1952	6	1,997,923	912.3	35
Dominican Republic	1966	3.5	585,000	457.9	18

Source: V. A. Oyenuga and L. K. Opeke (570)

but it is quite obvious that countries where cassava is largely produced should have no problem with undernutrition. The contribution of cassava to the caloric component of diets in many tropical countries is therefore enormous even when one recognizes that cultural practices, storage and marketing in these countries are still in the primative stage.

World Production and Consumption:

The annual global yield of cassava can be estimated at 70 million metric tons, from figures provided by Chadha (162). Assuming an average yield of 3.9 million calories per metric ton (570), the annual global production of calories from cassava alone would amount to 279,104 billion, enough to provide about 218 calories per day to every man, woman and child in the entire world. This means that with all its limitations on cultural and storage facilities, cassava alone could provide the world with about 8% of its daily caloric needs. Estimates from the Food and Agriculture Organization (FAO) of the United Nations are not far from the above figures. According to the 1968 Production Yearbook (293), the annual global production of cassava was 83 million metric tons. Applying the above computations to these figures, one would arrive at 10% as the daily contribution of cassava to global caloric needs. Coursey and Haynes (204) estimated the contribution of root crops to total diets of the world at 6% for the Near East, 11% for the Far East, 15% for Latin America and 29% for Africa, giving an overall average of 15%.

The significance of these relative figures is that world food or nutritional problems are not exclusively protein-related. There is a definite and widespread deficiency of bulk in the diets of millions of the world's population which many nutritionists define as undernutrition

or hunger. More specifically, sub-caloric intake is a significant component of the total food picture in the world. In this context, therefore, cassava as an inexpensive calorie source can contribute immensely to the world nutritional welfare by sparring limited resources which can be diverted toward proteinacious foods.

One useful way to evaluate the importance and potential of cassava is to relate its value to those of other alternative carbohydrate sources. Comparative figures on cost of production, yield of calories, proportion of food expenditure, etc., have been made between cassava and a number of competing carbohydrate sources. A nationwide survey in Ghana in 1952 (240) revealed that cassava and its products accounted for 12% of all food expenditures as compared with 17, 14 and 18% for cereals, meat, and fish, respectively. Cassava and its products accounted for nearly as much percent expenditure as did the rest of grains, tubers, and roots, all put together (240).

FOOD CASSAVA

Although cassava is believed to have originated in the new world tropics (643), its widespread cultivation and adaptability throughout the tropical world accounts in part for the key role it holds as a dominant food crop in tropical diets. That cassava occupies a staple status in most undeveloped economies is not difficult to document or explain; what is very surprising is the uniformity existing in the techniques of preparation and processing and the almost identical nature of the edible form from one tropical habitat to another. For example, gari, one of the forms of food cassava which has universal usage among some six countries in West Africa -- a geographical region

with over 200 languages and half as many distinct ethnic groups -- is very similar to farinha de mandioca in Brazil and the MesoAmericas. The question may be asked: Why has a food crop with such industrial and economic dimensions as cassava eluded the interest and priorities of industrialists over the years? Some of the answers to this question may be found in the limitations inherent in the nature of the cassava food which renders it a second rate crop in the social preference ladder of many countries. The limitations include the presence of a cyanogenic glucoside, linamarin, which on hydrolysis yields glucose, acetone, and hydrocyanic acid (HCN) which is poisonous if taken in high concentrations (119, 570, 590, 591). Another limitation is that cassava is largely, almost exclusively, a carbohydrate food and possesses other nutrients in far less than adequate amounts. Food cassava is perhaps as far removed from a balanced diet as is possible, and so it has earned a low preferential index among communities where protein deficiency is a dietary rule rather than an exception. Another possibility is that due to its bulky and perishable nature, cassava did not command enough attraction as a raw material for large scale export to developed countries in spite of its relatively low cost of production. For these and other possible reasons cassava has remained essentially a famine reserve crop, the tubers being about the only edible portion to humans. A glimpse of the potential of this crop, however, suggests that not only the tubers but also the leaves should play a more significant nutritional role in the diets of tropical countries.

Comparative Food Value of Cassava:

From the chemical composition of cassava presented in Chapter V (Tables 5-1, 5-2), it is quite evident that cassava is rich in calories and deficient in protein, fat and some vitamins and minerals. It should be pointed out that several other caloric sources in tropical diets share these same general characteristics but to a less extent. Some of the grain and root crops which compete with cassava for staple status in the menus of tropical countries are: yams, cocoyams, plantain, rice, millet, corn, and pulses (legumes). The yam, like the potato, is considered an underground stem while cocoyam is a corm. The comparative food value of cassava in relation to any of these alternate starch crops is unfavorable; however, the cost of production and yield of calories per hectare, per man-day or per capital investment, appears to be overwhelmingly in favor of cassava. The comparative risk due to disease infestation, drought or climatic uncertainties also tends to favor cassava. Table 5-9, in the previous chapter, shows the relative food and biological values of cassava vis a vis the other competing calorie sources. It can be noted from this table that cassava compares quite favorably with sweet potatoes in protein content, and total amino acid content, whereas taro or cocoyam has a distinct edge over cassava in all nutrients.

The protein quality of cassava tubers is inferior to most of the alternate starch sources. Native cassava users have developed ingenious systems (367) to compensate for the low protein content of cassava roots, and thereby, take advantage of all the above mentioned advantages of this crop and at the same time obtain a balanced diet.

In South America, the natives employ elaborate techniques to eliminate the prussic acid and detoxicate the roots for human consumption. These methods include prolonged fermentation, sometimes as long as 8-10 days, during which considerable microbial synthesis of protein occurs. The work done at the Tropical Products Institute, London, and by Gray and Abou-El-Seoud (346) showed that the protein content increased by a factor of 6-8 through microbial conversion. Gray (345) pointed out that such a system of microbial conversion of carbohydrates into protein is highly efficient; 15 times more efficient than beef, 12 times more efficient than poultry, and 4 times more efficient than milk. Pinto (604) showed that the microbial protein also possesses a very satisfactory amino acid composition from a nutritional point of view.

Strasser et al. (726) developed a process for growing yeast on hydrolyzed cassava and producing a dehydrated product containing 33% protein. They suggested that this low-cost protein (the processing cost, not including the cost of cassava, was estimated as 34.7 cents/kilo), can be incorporated with untreated cassava flour during the process of preparing native cassava dishes such as "gari" or "farinha de mandioca." Besides giving a meaty flavor to the product, it also improves the taste.

Of overriding importance in the chemical and nutritional characteristics of cassava is the presence of a glucoside often referred to as linamarin, which on hydrolysis releases free prussic or hydrocyanic acid (HCN). This HCN is poisonous to humans and livestock. Evidence for the latter has been observed by the author. When goats are fed browse composed of cut (and invariably) wilted cassava leaves, death

occurs rapidly -- maybe in a matter of minutes. However, goats can browse on cassava leaves and stems in situ without any apparent health hazard. It would appear that the hydrolytic enzymes are activated by bruise or wilting. The amount of HCN, and consequently the degree of cassava toxicity, varies with variety, the soil in which it is grown and the climatic factors predominating in the environment (371, 569). Both "sweet" and "bitter" varieties contain HCN although the "sweet" varieties are believed to contain much less of the poison; hence, these varieties can be safely consumed by humans without any elaborate fermentation or detoxification process. Pereira et al. (591) reported a strong correlation between bitter taste of the root and high hydrocyanic acid content. By tasting the raw cassava tubers, these authors found those varieties which tasted sweet had 4-7 mg HCN/100 g while those which tasted bitter had 29 mg/100 g, or more HCN. The range of concentration of HCN can vary from 10 mg to 370 mg/kg of fresh root (119). However, the peel or rind may contain up to 10 times as much HCN as the tuber core (569). The lethal dose for an adult human is estimated at 40-60 mg (535, 591). There is strong evidence that within varieties, climatic factors and age do influence the content of HCN. Oyenuga and Amazigo (569) found the HCN content of several varieties increased when planted in dry soils or harvested during dry weather rather than under wet conditions. This phenomenon may be a simple dilution effect.

The presence of HCN in cassava has far reaching significance, not only from agronomic, genetic and economic considerations, but also from a nutritional standpoint.

Edible Parts:

The primary source of food from cassava is the tuber; the central core is a starchy mass which can be prepared into food in a variety of ways.

Although the tuber is generally considered the predominant food source, evidence from the literature suggests that cassava leaves do contribute to the menus of certain communities in the Congo, New Guinea and Central Java. In these and other areas, the eating of cassava leaves has generally been associated with stress conditions imposed by climate, disease or war. According to Oomen (559), as much as 454 grams of cassava leaves are consumed per capita per day by some of these people. Chemical analyses have indicated that the cassava leaf is a rich source of protein, containing up to 30% on dry matter basis (Table 6-2). Leaf consumption, not only of cassava, but also of other sources like kang kung (*Ipomea reptans*), ferns, sweet potatoes, papayas and cocoyams, does not appear to be a generally popular habit among people in the tropics where greens can be found practically year round. However, kang kung leaves are a very popular vegetable in the Far East. This situation led Dr. Burgess (559) to ask, "How is it possible, that there is so much xerophthalmia in so green a country?" He was referring to Indonesia (559).

At a time when several sources of protein such as chlorella, seaweeds, protozoa and wax are being suggested as possible alternatives to meat in alleviating tropical malnutrition, the importance of readily available, cheaply producible sources such as cassava leaves must not be ignored. While these other alternative sources may hold some

TABLE 6-2. Average Nutrients in 100 gm Dry Matter of Green Leaves, Beans, and Fruits.

	Protein gm	Calcium mg	Iron mg	Carotene I.U.	Vitamin C mg
Green leaves[1] (amaranth, cassava, ipomea)	30	1,300	20	6,200	810
Beans (mung type)	27	160	7	150	0
Fruits[1] (banana, orange, papaya, mango, pine-apple)	5	140	3	4,500	315

[1]Data represents an average of all crop leaves or fruits mentioned.

Source: H. A. P. C. Oomen (559)

promise, the fact remains that tropical countries with year-round summer climate and abundant rainfall have no excuse for suffering from malnutrition and a deficiency of vitamin A. The abundance of highly nutritious green vegetables and fruits in these areas and their untapped potential have been appropriately referred to as "the hidden wealth" (559).

The dietary habits of people are very difficult to change, but industrial means should be sought to blend cassava leaves into acceptable edible forms which would entice consumer acceptance. Educational programs should then emphasize the nutritive value of such new products through advertisement and other available media.

Direct or Immediate Consumption:

Cassava roots of the sweet varieties may be eaten raw since they are relatively high in soluble carbohydrates and low in HCN. Roots of these varieties can also be cooked and when boiled they somewhat resemble potatoes. In Ghana, ampesi (boiled cassava) is often eaten in combination with roasted peanuts, fish, stew, or alone (240).

More elaborate preparation methods are used for bitter varieties with the major objective being detoxification, since these varieties are usually high in HCN. Surprisingly, there exist few reports or evidence of fatal accidents resulting from direct human consumption of raw, bitter cassava, presumably because people have learned to select varieties either by experience or on the basis of morphological characteristics (162).

Bitter varieties can be cooked, peeled and sliced into shreds. These shreds, measuring about 5 cm long and 1 cm wide, when wet, cling together like macaroni. They are packed into hand-woven baskets with

lids and immersed in running water for 24 hours. Then they are washed several times and eaten with coconut, oil, peanuts, spices, vegetables and other condiments -- all mixed together. They can also be eaten alone as a snack. This form, which is called Ji Akpu or simply Akpu in Nigeria (Ibo), can be dried and stored indefinitely. Rewetting restores it to its original soft form and thus it can be combined with a variety of condiments including oil, spice, greens and salt.

Another form in which cassava may be stored against famine is called Kokonte (dried cassava) in Ghana, Achicha in Nigeria, and Carima in Brazil. The peeled roots are dried in the sun for several days until they become quite brittle. They may be stored in this form, often with a heavy risk of insect pests which bore holes into the dry chunks, or they may be ground into a flour and stored. The flour can be moistened, molded, boiled and then pounded into fufu and eaten with soup. This form of cassava is considered perhaps the least sophisticated and is generally eaten by humans only in the event of nutritional stress, since the end product is often brown or black and may posses an objectionable odor. Yam flours (from Dioscorea) are definitely preferred to the cassava analogue and have been mechanized and commercialized in tropical African countries.

The preceding forms of food cassava are essentially domestic processes where a household harvests a plot of cassava and prepares what it needs for immediate consumption or storage. They are not marketed usually except in cases of overproduction when a family would normally sell some in order to purchase other items of food.

Other forms are more commercial and naturally more widespread. Cassava starch, which is bagged and marketed in wet, sometimes unhygienic conditions, belongs to this category. In preparing it, the fresh tuber is washed, cut into pieces 10 to 15 cm long and fermented in large pots for 3 to 4 days. Fermentation is frequently performed on a large scale in stagnant ponds and creeks. A layer of foam can be observed on the top of the fermentation vat, presumably as a result of the evolution of gaseous HCN, volatible fatty acids and a variety of other products (18). During this process the hydrocyanic glucoside is destroyed and the pulp loosens and separates easily from the peel which then looks like a hollow cylinder. The central fibrous shaft also loosens and is removed during washing and subsequent dialysis. The resulting white starch is heaped into piles and reduced in moisture content by applying pressure. It is then bagged as an ammorphous white mass, which is high in moisture content, and transported to market or consumed. Storage is difficult for this kind of cassava product. A period of 2 to 3 days is considered maximum for use; beyond this period, putrefaction sets in and the quality deteriorates.

For immediate consumption, this starch can be dextrinized by boiling in water and then pounded into "fufu", a product similar in consistency to mashed potatoes. Fufu is eaten throughout tropical Africa in conjunction with a cooked mixture of meat, oil, vegetables, spice and water referred to as "soup". Cassava fufu is considered "heavy" in comparison to yam (Dioscoria) fufu or even cocoyam (Colocasia) fufu.

Storage Forms of Cassava:

In Africa, the most widespread and commercial form of food cassava is a fermented product called "gari." The evidence for this comes from the fact that unlike other forms of cassava, gari has no localized names throughout West Africa. In this form cassava has received the greatest attention industrially, both domestic and abroad. It has also been intensively studied from the point of view of fortification, mechanization, and fermentation. The Federal Institute of Industrial Research (Nigeria) has made a number of pilot and feasibility studies on improving, facilitating, expanding and modernizing the processing of gari. The domestic or home process consists of grating the peeled root to a fine mash. This mash is then placed into jute bags and the moisture extruded by applying pressure. After 4 or 5 days, the mash, which now has a moisture content of about 50%, is spread out, sieved and fried, sometimes with the addition of red palm oil for flavor. In the traditional sense, the addition of soil prevents burning and adds to the flavor. It is not certain whether the fortification which accompanies it is intentional. Nevertheless, palm oil is a rich source of vitamin A. During frying, the particles are continually stirred to prevent clumping or burning. The particle size of gari is 10-80 mesh, depending on the grating diameter.

The fermentation period for gari processing appears to be the most important set-back in efforts to industrialize it. Two stages of fermentation have been described by Akinreie et al. (18). First, a hydrolytic action by Corynebacterium manihoc which causes the breakdown of cyanogenic glucosides liberating gaseous HCN. The second

stage of fermentation involves the fungal activity of Geotricum candida which produces aldehydes and esters that impart the characteristic taste to gari. Reduction of the fermentation time has been accomplished by Collard and Levi (188) by inoculating the fermentation mixture with liquor from a three-day fermentation broth. This enabled them to shorten the fermentation time to 24 hours without any apparent loss in quality of flavor.

The processing method described for the "village" factories has been modified by indigenous industries, particularly the Federal Institute of Industrial Research. They demonstrated that when cassava peeling was done mechanically, loss due to peeling was reduced from 30% to 5%. The time required for making gari has also been increased. A pilot plant described by Akinrele et al. (18) can produce a ton of gari daily from three tons of cassava root.

One factor contributing immensely to the popularity of industrially processed gari is that storage is possible for as long as six weeks due to its low moisture content. Other contributing factors are the ease of transportation, the hygienic conditions under which it is processed and stored, and the ease by which it can be prepared for eating.

Gari, when prepared for home consumption, is frequently soaked in cold water and eaten like a cereal, often with peanuts, cashews, or other similar snacks. However, this practice should be discouraged from a nutritional point of view since it provides little other than carbohydrates. By filling the stomach with bulky gari taken in this manner, an individual can quell the pangs of hunger and yet be starved for nutrients. Unfortunately, in West African countries, this form

appeals to urbanized low-income people, particularly unmarried people, who find it very convenient and time saving. Other forms of preparing gari include soaking it in hot water to make fufu, popularly known in Nigeria and Ghana as Eba. The soaked gari can swell to three times its volume and this swelling ratio determines to some extent its price value.

The Nutritional Value of Gari:

Gari has a higher nutritional value per unit consumed than cooked or raw cassava because it has a lower moisture content and some nutrients are accumulated as a result of fermentation. Table 6-3 compares the values of peeled cassava root, village-processed and industrially-processed gari. It is evident from this table that the industrially-processed gari has a lower moisture content, a higher proportion of NFE, crude protein, calcium and fiber, but a lower HCN and ash content than village-processed gari or unprocessed cassava.

The most important advantages of the industrial gari would be an increased storage ability, a slight increase in nutrient content, and a safer margin with regard to HCN. The most serious disadvantage is its physical characteristics as they relate to consumer acceptability. Adeyinka and Akran (8) reported on a consumer acceptability test conducted on industrially prepared gari and found a widespread consumer rejection on the grounds of flavor, color and texture. There were many lumps in the garifyer and the gari floated in hot water, thus making it difficult for preparation of Eba (fufu). The color turned black after 2 days due to a high content of phenolic compounds and HCN. Many consumers detected the taste of raw starch; perhaps a result of the accelerated fermentation process that was reported above.

TABLE 6-3. Comparative Nutritive Values of Unprocessed Cassava and Gari.

	Peeled root	Village gari	Industrial gari
Water (%)	71.50	14.2	8.4
Nitrogen-free extract (%)	26.82	81.8	87.0
Crude fiber (%)	0.12	1.4	2.3
Crude protein (%)	0.74	0.9	1.5
Fat (ether extract) (%)	0.13	0.1	0.1
Ash (%)	0.69	1.4	0.9
Calcium (mg/100 gm)	33.00	17.7	45.6
Phosphorus (mg/100 gm)	80.00	57.2	56.9
Iron (mg/100 gm)	0.07	2.0	2.2
HCN (ppm)	----	19.0	10.0

Source: I. A. Akinrele et al. (18)

While eating habits and consumer preference should be duely considered in developing new food products, it should be noted, however, that consumer skepticism about or even aversion to new products is neither new nor insurmountable. Similar objections were raised to factory-processed spaghetti by Italian and European consumers. The same sentiment is expressed in favor of mortar-prepared yam fufu over yam flour. However, economic realities, particularly price differentials, should swing the scale in favor of the mass-produced item.

Although industrially-processed gari represents a considerable improvement in nutrient content over the hand- or village-processed gari, it can not be considered a balanced ration when eaten alone. This fact becomes obvious when comparisons are made with equivalent cereal substitutes Almost all gari in West African markets today come from thousands of semi-domestic mills scattered over the area and collected by traders who truck it in sacks to the major metropolitan centers. Naturally, the nutritive value and chemical composition varies widely. Questions arise as to how much fortification gari can stand, whether gari should be fortified in the first place, or merely taken as a carbohydrate source. However, gari has been fortified to a reasonable extent and thus provides a variety of nutrients in substantial amounts. Doku (240) reported a table of chemical composition for fortified gari which shows that at this level of fortification, gari had a comparable composition with some conventional grain products such as macaroni and corn grits, and it could compete favorably at the nutritional level with any of these alternative caloric sources (Table 6-4).

TABLE 6-4. Chemical Composition of Fortified* Gari and Some Selected Cereal Products.

	Fortified gari	Enriched macaroni**	Enriched corn grits**
Water (%)	7.3	49.23	35.5
Protein (%)	7.9	4.61	1.2
Carbohydrates (%)	77.9	30.00	11.0
Calcium (mg/cup)	73.3	14.00	2.0
Phosphorus (mg/cup)	140.9	----	----
Iron (mg/cup)	3.3	1.40	0.2
Thiamine (mg)	0.24	0.23	0.05
Riboflavin	1.0	0.14	0.02
Vitamin A (I.U.)	16.0	----	150.00
Niacin	----	1.80	0.5
Calories	341.0	190.00	125.0
Fat (%)	13.3	0.76	----

*Fortified with minerals and vitamins.
**Percentage equivalent calculated by author.

Source: E. V. Doku (240) and USDA (772)

The most important significance of gari in a developing economy is its cheapness. It costs less to produce or buy gari (or cassava in any form) than corn, bread, yams and other substitutes on a calorie basis. Jones (409) reported that on the average it costs 5 times as much to purchase 1000 calories of yams than the same amount of calories from gari, twice as much as corn, and three times as much as rice. Although these comparisons were made in Orulu and Owerri areas of Nigeria, more or less the same situation exists in other areas where cassava is produced. In Ghana, kokonte is cheaper than gari, maize, sorghum, white rice, or cocoyams. In Dakar, dry cassava roots are also cheaper than millet, corn meal or rice. In Ruanda-Urundi, it is cheaper than sweet potatoes, sorghum, or Irish potatoes. In various parts of East Africa, fresh or dry cassava root is cheaper than bananas, corn meal, or cassava flour.

This relative cheapness is and ought to be regarded as an economic advantage in the sense that replacing more expensive calorie sources with less expensive gari might allow extra cash to flow into other rich nutrient sources such as fresh vegetables, beans, fish, etc. In practice this economic logic does not hold true. In the past, the relative cheapness of gari has been misconstrued as dangerous (409) on the wrong impression that cheapness and availability might encourage overconsumption of cassava as monodiet, thus excluding other required nutrients. In a situation where a balanced diet is more of a random rather than a conscious objective, this argument may have some validity. However, the greatest obstacle confronting cassava products is the fact that their relative cheapness affects their consumer preference index,

particularly among sophisticated and invariably educated consumers. It is a common practice in many countries to import potatoes, peaches, peas, etc., at high prices in preference to the local and cheaper substitutes which furnish comparable nutrients.

Gari, as described in this text, closely approximates certain other food products of cassava consumed in other countries. Brazil, for example, has what is called "farinha de mandioca", which for all practical purposes, is gari. Doku (240) noted that the only difference between the two was that farinha was produced more rapidly with less souring or fermentation than gari. This is done by using heavy pressure to squeeze out the water from the starch, rather than drain it out more slowly.

Miscellaneous Cassava Food Products:

Macaroni.--A more successful enrichment cassava product was reported by Bains et al. (79) on work done in India. Tapioca macaroni or "synthetic rice" is an enriched tapioca product containing 18-20% protein when tapioca is blended with peanut flour, nonfat milk solids, vitamins and other nutrient-rich items.

Gaplek.--Holleman and Aten (371) reported a number of other "conserved" cassava products. These include Gaplek in Indonesia. Gaplek has the same basic description as kokonte (or carima) that was discussed earlier. It is also popular in Madagascar.

Bread.--Cassava bread or couac is made in Latin America somewhat as a by-product of crude tapioca manufacture. It is equivalent to gari or farinha in preparation and use. The tapioca flour which accompanies the processing is mixed with wheat or rice four and used for making bread and other bakery products.

Cassaripo.--In the West Indies and Brazil, the fluid or juice squeezed from the grated cassava is concentrated into a product known as cassaripo or tucupay. This product is believed to be rich in nutrients. It appears that fortification of this paste or liquid form could provide a limitless range of nutrients. Some countries dip fish or meat into the broth to preserve it, and naturally, the resulting broth is rich in nutrients -- something resembling the African "soup".

Tapioca.--Tapioca is the most universally known and accepted cassava product. It is made by partly gelatinizing cassava starch granules by heat treatment of the moist flour. The end products formed from milling these gelatinized lumps may be pearls, flakes or round beads with a diameter of 1 to 6 mm and frequently referred to as seeds or pearls (371). When the gelatinized lumps are milled a finer grained product is obtained called "grist". Most of the industrial tapioca starch is now produced in the grist-like form rather than pearls, flakes or beads. In this form it is used in the manufacturing of jello, salad dressings, puddings, pie fillings, baby foods and candy making.

RESEARCH RECOMMENDATIONS

Further research on the nutritive adequacy of cassava can be approached from 5 main angles as follows:

1. Limitations on processing cassava for human consumption. Rapid detoxification of prussic acid in cassava by chemical or bacteriological processes would shorten the processing time, thus eliminating the tedious, and invariably, unhygienic village processing. Some work has

been initiated in this direction. The magazine "West Africa" (April 23, 1971) describes a gari processing plant that was developed jointly by Newell Dunford Engineering, Ltd., and the Nigerian Institute of Industrial Research: "The plant removes prussic acid from the cassava ..., doing in one operation what takes a villager several days." Fortification of the commercial product can also be envisaged in this effort. Addition of high quality oils and meat analogues from other plant sources should also be investigated.

2. Some information is needed on the biological value and nutritive ratio of menus in which cassava is a predominant or subsidiary item. Fufu meals (including soup) should be completely evaluated, not only by proximate analysis but by actual feeding experiments. It should be possible to initiate balanced or metabolism trials, nitrogen balance studies and possibly using isotopic tracers in experimental animals. There is a definite need for information relating to the utilization of cassava at the cellular level. Such research is either scanty or non-existent at the moment.

3. There is also a health-related aspect of feeding cassava that has not been fully explored. There is a strong possibility that residual poison can accumulate in the body through continued consumption of cassava products, since fermentation processes do not eliminate all prussic acid from the food. Cassava consumption has been associated with the incidence of goitre in Nigeria but the goitrogenous substance has not been identified and this finding has been confirmed from other parts of the world.

4. Side by side with research in facilitating and modernizing cassava processing should be an effort by food technologists, home economists and nutritionists to develop new menus in which cassava products can feature adequate proportions to ensure balanced rations. This would create more variety for their use as well as improve their food value, flavor and taste in a manner that should attract the more sophisticated sector of the consuming community. For example, soaking gari or cassava flour in beef or chicken broth, adding fresh tomatoes, vegetable greens and cheese to the mixture should produce a fairly balanced meal. This mixture can be spiced, salted and baked to produce a consistency similar to a pie. The inclusion of cassava leaves into regular meals should be encouraged. By appropriate detoxification, drying and milling, cassava leaves could be processed into a form that resembles "bitter leaf". This is a popular green used in making soup by people in West Africa.

5. The possible use of cassava as a substrate in fermentation processes to produce microbial protein deserves at least some speculation. Champagnat et al. (163) initiated a similar culture, using wax and crude petroleum products as energy sources to grow microorganisms. Cassava fermentation studies by Collard and Levi (188) identified the actions of Corynebacterium manihoc and a fungus Geotricum canida. Protozoa do not seem to be involved in this fermentation process and it appears questionable at this stage what practical role cassava could play as a possible source of microbial protein. However, there are numerous lactic acid bacteria and fungi that can utilize the fermentable carbohydrate. In addition to forming lactic acid, some of these organisms

produce small amounts of vitamins and other nutrients. Work with such "pure culture" fermentations would promote good manufacturing practice and at the same time would yield products of more predictable and uniform flavor. Better control of the gari fermentation would reduce the problem of spoilage and "off fermentations". Work is needed in this area.

CHAPTER VII

Utilization of Cassava as a Livestock Feed[1]

Cassava has been used in livestock feeds for many years and increased as a good source of calories prior to World War II (60). In 1969, FAO established the world production of cassava roots at 85.6 million metric tons (Table 7-1), but the quantity used for animal consumption is not well established. Some nations ranking very high in production use relatively small quantities for animal feed in relation to their production. Imports into the U. S. for animal feeding are nil, whereas large imports occur into certain countries in Western Europe (60). The Federal Republic of Germany, Belgium, France and the Netherlands imported 883,514 metric tons in 1966. The valuation was 57.5 million dollars.

Germany alone imported 701,709 tons or 79.4% of the total imported into Western Europe. Seventy-five percent of imported cassava into Germany was in the form of dried roots and the remaining 25% was in the form of meal or flour. It was estimated that approximately 462,000 metric tons of cassava were used in the formulation of feedstuffs for animals, which represented 10% of the feedstuffs used in Germany in 1966. Cassava was utilized as about 3% of the feedstuffs in the Netherlands.

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[1]Prepared by R. W. Seerley, Department of Animal Science, University of Georgia, Athens, Georgia.

TABLE 7-1. 1968 World Production Acreage and Yield of Selected Crops.

	World hectarage (million hectares)	World yield (100 kg/ hectare)	World production (million metric tons)
Cereal grains			
Wheat	227.5	14.6	332.5
Rice (paddy)	132.2	21.5	284.2
Maize	106.0	23.7	251.1
Millet and sorghum	111.2	7.7	85.1
Barley	74.9	17.4	130.7
Oats	32.3	16.8	54.2
Rye	22.4	15.0	33.4
Root crops			
Potatoes	22.8	138.0	315.5
Sweet potatoes & yams	16.0	84.0	134.4
Cassava	9.8	87.0	85.6
Sugar beets	7.9	31.9	251.2
Legumes (pulses)			
Soybeans	33.6	13.0	43.6
Pigeon peas	2.9	6.3	1.8
Dry beans	22.7	4.7	10.7
Peanuts	17.6	8.5	15.0
Chick-peas	10.8	6.9	7.4
Cowpeas	2.8	3.9	1.1
Dry broad beans	4.7	9.9	4.6
Dry peas	8.8	11.5	10.1

Source: FAO Production Yearbook, 1969 (295)

The maximum use of cassava in complete feeds is officially controlled in Germany and the Netherlands. The maximum content in complete feeds by feed manufacturers is as follows:

	Germany (%)	Netherlands (%)
Poultry	20	7.5
Swine	40	
Pigs, 25-50 kg		7.5
Pigs, 50-100 kg		15.0
Sows		5.0
Calves		5.0
Dairy cows	25	20.0

In Belgium, the maximum content of cassava is said to be about 5% of complete feeds. The reason stated for limiting the quantity in animal feeds in Western Europe is that it is principally a fattening agent. Thus, German livestock feeders were using most of the cassava in swine diets. Limitations were imposed to insure lean muscular carcasses.

TYPES OF CASSAVA PRODUCTS USED IN ANIMAL FEEDS

There is a variety of cassava products used as feedstuffs in the feed manufacturing industry. The most common forms used are chips, broken roots, pellets, slices and meal.

Chips:

Cassava chips are the most common form used in the feed industry. The standards used in trading are 13-14% maximum moisture, 5-6% maximum crude fiber, 3-5% maximum ash and a minimum of 70% starch. No standard is placed on protein content. The size of chips varies, but the length

should not exceed 4-5 cm. Longer chips have a tendency to jam the mixing equipment. The chips consist of the root and should be well-peeled, washed and dried. German feed manufacturers observe a wide range in the quality of the chips which are purchased from different parts of the world.

Broken Roots:

These are similar to chips in appearance, but they are generally thicker and 12-15 cm long. The broken roots have the same feeding value as chips. The major problem is the jamming of equipment.

Pellets:

Cassava roots or chips can be pelleted to form a shape of approximately 1 cm in diameter and about 2 cm in length. The use of pellets is not extensive because of the cost, but some manufacturers like them for these reasons:

1. Freight rates are lower on the pelleted cassava.
2. Handling is easier and handling charges are lower.
3. Storage space requirement is 20-25% less than space needed for the same weight of chips.
4. The quality of cassava is more uniform.

There is a trend towards the use of pellets (60). It appears that pelleting will continue to increase because of the advantages in handling the cassava.

Cassava Meal:

Cassava meal is the residue of roots and chips after processing in the manufacture of starch. Although starch is removed, the meal contains as much as 55-65% starch. The quality is often inferior because of a greater contamination of sand and residues of the processing.

Cassava Leaf Meal:

Limited use has been made of cassava leaf meal which is composed of the leaves and small tender stems. The physical appearance of leaf meal is similar to that of alfalfa and its composition is similar to alfalfa meal. If good harvesting techniques can be developed, cassava leaf meal has good potential as a protein and vitamin supplement.

NUTRITIONAL VALUE

The principal discussion on chemical composition of the roots and leaves is presented in Chapter V. However, a few very brief statements should be made in reference to animal feeding.

Roots are very high in starch content, but very low in fat, protein, minerals and vitamins. On a dry matter basis, the caloric content of cassava is about equivalent to corn, but its levels of lipids, protein, minerals, and vitamins are much lower than corn. Therefore, feeds with cassava roots as the source of energy need to be fortified to nearly meet the animals' requirements for lipids, proteins, minerals and vitamins and let the quantity of these nutrients in cassava appear as a margin of safety in a balanced diet. If a variety such as Llanera has more protein, then the protein of the root would contribute to meeting the requirement.

The lipid requirement will likely be met by the addition of the protein source, yet chemical analysis should varify that the requirement is met.

Protein is a major deficiency of cassava roots. An adequate supply of high quality (balance of essential amino acids) must be available for feeding monogastric animals. The protein quality is not a critical

matter for feeding ruminants, but a large supply of protein or protein substitutes is necessary to balance their diet.

Cassava is deficient in most macro minerals for animal diets. However, potassium is relatively high and could possibly cause an adverse mineral interaction, especially in poultry diets. Level of most trace minerals in cassava is not known, but it is assumed that most trace minerals would be very low also.

The vitamin content of cassava roots has not been widely studied, but there appears to be only trace amounts of vitamins in the roots. All animal diets would require another source of vitamins.

Young leaves of the plant, generally of the sweet varieties, are sometimes used by Africans as vegetables and in some countries the leaves and shoots are fed to livestock (162). The leaf is palatable and is readily consumed by all species of livestock, but ruminants can utilize more than nonruminants because of their ability to utilize the fiber.

Leaf meals from Jamaica and Brazil have been analyzed for nutrient content also (652) (see Tables 5-15 and 5-16). The leaf meals tested averaged 25 and 27% crude protein, which is higher than found in dehydrated alfalfa meal. Unfortunately, methionine is low in the leaf, like in the root and methionine would probably be deficient when the two were used together in a feed for nonruminants. It is noted that there was a wide range in levels of most nutrients from sample to sample. The variation could cause problems in feeding livestock unless standards of quality control were established. Johnson and Raymond (403), based on the work of Van Veen (779) and Bangham (84), reported on the level of cyanogenetic glycoside in the leaves. Cooking removed the glycoside.

Nevertheless, the HCN could be a problem where it is desirable to feed the fresh, uncooked leaves to livestock. Barrios and Bressani (91) reported that the cassava leaf is relatively rich in protein, ash, calcium and ether extract, but it must be detoxified of HCN before it is used for animal feed.

The feeding value of cassava leaves is similar, in general, to that of alfalfa meal (594). The crude protein, NFE and ash are slightly higher in the cassava leaf meal, but alfalfa has considerably more fat and fiber. Obregon and Juarez (553) reported that cassava leaf meal had more fat and protein and less ash and fiber when harvested at 217 days than the leaf meal harvested at 305 days. The meals had more calories and less fiber than alfalfa.

Hydrocyanic Acid:

Chadha (162) stated that the bitter principle in the root is an unstable cyanogenetic glucoside which undergoes hydrolysis, especially in the presence of enzymes, to yield hydrocyanic acid and glucose. The glucoside content of roots is variable, depending on variety, and the type of soil and plants where the plant is grown. The amounts range between harmless to lethal. One hundred varieties in Tanzania varied from 1.6 to 33.4 mg per 100 g of fresh root. As much as 77 mg of HCN per 100 g of root has been found in India.

In some varieties the glycoside is more or less evenly distributed between the peeling and the flesh of the root, whereas in others, it predominates in the peeling (403). "Bitter" cultivars are usually much higher in HCN content than the "sweet" cultivars. Average HCN in the sweet cultivars is about 0.007% while it may be 0.02 to 0.03% in the bitter cultivars.

The level of HCN which causes toxicity in animals is probably known by some animal producers, but the toxic level has not been widely studied and cannot be given in this report. Oyenuga and Amazigo (569) reported the levels of HCN (0.034-0.1121%) found in six varieties would be toxic to livestock. Nicholls (535) stated that 0.06 g had been found to be the smallest lethal dose to adult animals. Johnson and Raymond (403) suggested the lethal dose of HCN may be 1.4 mg per kg of body weight. However, it is generally considered that 40 mg of HCN is enough to kill an adult human being (591).

The HCN content of cassava is discussed here because it could be a serious problem in animal nutrition. However, the use of sweet cultivars and proper treatment to liberate the HCN should be adequate to insure the safe feeding of cassava.

LIVESTOCK FEEDING EXPERIMENTS

Swine:

The value of cassava in swine diets has been recognized for many years and several reports appear in the literature since 1900 (62, 71, 157, 191, 318, 377, 440, 486, 487, 488, 503, 510, 570, 765, 780). The predominant portion of research involves comparison of diets with cassava and diets containing other roots, tubers or cereal grains. One of the earliest reports (765) emphasized that cassava is too carbonaceous to be the best feed for growing pigs, and when fed to such animals it should be mixed with nitrogenous feeds which will furnish nutrients for bone and muscle. Many farmers used cassava exclusively during the finishing period and found it very satisfactory. The pigs ate cassava greedily and preferred it to corn when both were placed

before them. The pork was very white in color, of fine flavor, and, though perhaps not quite so firm as that from corn-fed hogs, it was firmer and shrunk less in cooking than that from animals fed cowpeas or peanuts (765).

In 1928, a trial was conducted by Mondonedo (510) to compare corn and cassava when used as 20% of a swine diet. Other parts in the diet consisted of rice bran (70%), copra meal (8%) and shrimp (2%). In a 75-day test with heavy-weight pigs, the pigs fed the diet with cassava gained 8% faster, ate 9% more feed and required 9% less feed per unit of gain than those pigs receiving the diet with corn. Feed cost per unit of gain was 11% less with the cassava in the diet. However, the carcasses were apparently superior in the corn-fed group.

In 1940, Asico (71) used a similar trial to that of Mondonedo to compare cassava with corn. His trial was much longer (210 days) and young weanling pigs were used. Pigs receiving the cassava diet gained 90% of the gains achieved by those fed corn and feed efficiency was decreased approximately 5%. He concluded that "gaplek meal" was a good substitute for corn in rations for growing pigs if the price was 95% that of corn.

Oyenuga and Opeke (570) evaluated uncooked and cooked cassava with guinea corn or sorghum in diets for growing pigs. In this test, the attempt to feed equal nutrients by controlling the quantity of feed may have had some influence on the findings. Nevertheless, they concluded that cassava was equal to sorghum and raw cassava was as palatable and equal to the cooked cassava. However, there were two cases of posterior paralysis in the raw cassava group. The cause was not reported. The

pigs fed cassava had slightly more fat in the carcass, but there was no appreciable difference in the quality of fat as indicated by iodine number.

In a later trial at the same station (503), sorghum or maize was replaced by dried cassava at 32, 37 and 40% of the diet for pigs weighing 23-36, 37-55, 56-75 kg, respectively, which represents treatment one. Treatment two had 10% more cassava in the diet at each weight increment than treatment one. Pigs fed the lower level of cassava gained 1.8% slower. Feed conversion was approximately the same for treatments 1 and 2, but pigs fed the higher level of cassava required slightly more (3%) feed per unit of gain. The cassava-fed pigs had a lower carcass grade because of excess backfat. Feeding cost per unit of gain was lower with cassava because of the high prices of grain for human consumption. Prices of cassava were based on the price of fresh cassava plus the drying cost. The dried cassava was stored six months without any indication of deterioration.

Modebe (503) also reported good, yet limited, use of cassava in swine diets. He found that a level up to 50 to 55% of the diet can be supplied by either wet or dried cassava.

The most recent and extensive swine research with cassava has been conducted in Colombia, S. A., by Maner and co-workers (486, 487). In experiments 1 and 2, the practice of feeding raw cassava and a protein supplement free-choice was compared with a basal corn completely mixed diet. The feeding of protein supplement with cassava was tested two

ways by feeding ad libitum or controlled feeding. The results were that, in both experiments, pigs ate excessive quantities of protein supplement when offered ad libitum and balanced their diet at nearly 25% crude protein, which is more than necessary for good growth. Rate of gain was nearly the same between treatments in both experiments, except those fed raw cassava free-choice and a controlled quantity of protein supplement gained slightly slower in both experiments. Feed efficiency was improved with the cassava and free-choice feeding. Feed efficiency is usually improved by feeding corn free-choice also, therefore, the improvement observed may not be entirely due to cassava, per se, in these experiments. It is obvious that pigs performed very well with the free-choice feeding and some method of controlling protein intake is essential for economical gains. Limit feeding of supplement may be practiced or the palatability of the supplement may be decreased by using higher levels of salt, meat meal and alfalfa meal.

In experiment 3, cassava was offered ad libitum and variations were used with protein supplements. There was no consistent advantage of adding higher than recommended levels of vitamins and trace minerals. The use of cottonseed at 25% of the supplement appeared to be an acceptable substitute for some of the soybean meal, however, feed required per unit of gain appeared to increase with the cottonseed meal. One problem encountered in all three trials was the low consumption of cassava at the start of the trials by young pigs. If supplement was available free-choice, they readily ate the supplement. A period of time may be necessary for young pigs to become adjusted to the feeding of cassava at high levels.

Dried raw cassava was fed free-choice with six different protein supplements in experiment 4. In general, reasonably good performance was achieved with soybean meal, meat meal, blood meal and cottonseed meal or fish meal and cottonseed meal. Rate of gain was inferior with cottonseed meal alone. Pigs in all treatment groups overconsumed protein during the entire experimental period and especially during the first 28 days.

In experiment 5, dried raw cassava was substituted for 33, 66 and 100% of the corn in 16% crude protein diets. A factorial design was used with the other variable being 0 or 10% cane molasses. It was used to evaluate the effect on reducing dustiness and improving the palatability of the diets. Each increase in level of dried cassava caused a corresponding decrease in average daily gain with 0 or 10% molasses. The addition of molasses caused an increase in feed consumption by 13% and increased daily gains on an average of 10%. The quality of protein improved with each higher level of cassava yet there was a decrease in gain and no consistent improvement in feed efficiency. Therefore, they concluded the depression was directly related to the utilization of cassava.

In another experiment, silage was made with fresh roots or a combination of the whole plant (roots, stalks and leaves). Cassava and a standard protein supplement were fed free-choice to three different treatment groups. Pigs receiving the root silage gained slightly faster on less feed than those given fresh cassava and supplement; therefore, silage appears to be a good alternative way of feeding cassava. The stalk and leaves reduced consumption of the

total plant-silage and gains were slower and feed per unit of gain increased. The stalks were not suitable in the pig feed.

One experiment was conducted by feeding sows cassava during gestation and another test evaluated cassava in lactation diets. Both trials had limited numbers of animals, thus the results were variable and conclusions could not be made. Yet, there is every reason to believe cassava can be used in gestation and lactation diets. Some additional research is needed to establish the proper supplementation of cassava for breeding animals. Proper fortification of leaves, tender stems and roots should yield a good diet for breeding swine.

Castillo et al. (157) also studied cassava silage as a feed for growing swine. A chemical analysis of the material was made before ensiling and periodically after ensiling. There was some loss of nutrients in the runoff solution. In feeding trials, the use of cassava was satisfactory in the diets. Forty percent of the diet was cassava and other ingredients were used to make a diet similar to a diet with corn. However, the diet with cassava undoubtedly had superior protein quality. Pigs fed the cassava silage diet gained faster and required less feed than those fed the corn diet. While daily gains were relatively slow on all diets, it is apparent that silage can be used in swine diets.

Research reports pertaining to the use of cassava leaf meal in swine diets are very limited. Velloso et al. (780) found cassava leaf meal could satisfactorily replace alfalfa meal when used as 5% of a diet for finishing pigs.

Although by-products of the manufacture of starch from cassava have been used for many years in livestock feeds, there appears to be

very few tests recorded. Forty years ago, Fullerton (318) reported the following conclusions concerning the use of tapioca (cassava) meal in swine diets.

(1) High grade tapioca flour proved to be satisfactory as far as its palatability and other dietetic properties.

(2) It may be regarded as suitable to replace corn or barley up to at least 25% of the total ration.

(3) The bacon and hams from pigs fed the tapioca were distinctly better than those from corn-fed pigs.

(4) At current prices, replacement of corn with tapioca resulted in a sensible reduction in the cost of feeding swine.

Shortly after Fullerton's test, Howie (377) reported similar results with tapioca (cassava) meal.

Poultry:

Properly fortified cassava meal should be an acceptable feed ingredient in poultry rations, yet there are only a few research articles. Some of the earliest research with chicks was conducted in the Philippines (739). A high mortaility rate affected the experiment, however, the surviving birds did not grow as fast on cassava refuse meal as those fed rice bran. The diets consisted of 6 parts cassava refuse meal or rice bran, 2 parts corn and 2 parts shrimp meal. The cassava refuse was approximately 77% the value of bran, but a combination of the two was 92% the value of rice bran alone. However, Temperton and Dudley (752) reported laying hens had tolerated substitution with cassava meal up to 40% of corn meal, wheat middlings and oats.

In 1951, seven experiments were reported from a study in Guatemala (702). Cassava meal (by-product of starch manufacturing) was used in several different types of diets. The diets and results are shown in Table 7-2. In three of the seven tests chicks fed corn gained significantly faster than those fed cassava meal and feed efficiency was usually higher in the corn treatment group. However, they concluded that growth rate of the chicks fed cassava meal and the efficiencies of feed utilization were satisfactory and the meal could be used to replace corn in baby chick diets. The highest percent of cassava meal in any diet tested was 47.5%.

Klein (425) found that cassava meal could be used up to 10% of chicks' diets with satisfactory results. Vogt's (805) findings also indicated a level of 10% cassava meal was satisfactory in chick diets, but levels of 20% or more depressed gains. A level of 20% cassava meal was satisfactory in layer diets. Vogt concluded that Axelsson's digestibility values were more accurate than values reported by Fangauf. Table 7-3 shows the values in Vogt's paper.

Soares, Campos and Conrad (691) studied dried cassava meal and wheat middlings as carbohydrate substitutes for part of the ground corn in chick diets. Substitutions were made in increments of 6% of the diet. Cassava meal and soybean meal were used to replace corn and equalize the crude protein content of the diets. A maximum of 42% of the corn was replaced. There was no statistical difference in rate of gain between treatments, but chicks fed diets with 10% of the corn replaced by cassava meal had the fastest daily gain. Feed efficiency was best when the substitutions were between 0 and 30% of the diet. However,

TABLE 7-2. Effect of Cassava Meal in the Baby Chick Diet.

	Experiment 1		Experiment 2		Experiment 3		Experiment 4		Experiment 5		Experiment 6		Experiment 7	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Ingredients (percent)														
Corozo oil meal[1]	40	40	40	40	30	30	30	30	----	----	6	6	30	30
Sesame oil meal	25.5	25.5	25.5	25.5	25	25	20	20	37	37	37	37	15	15
Cottonseed oil meal	----	----	----	----	----	----	----	----	----	----	----	----	15	15
Menhaden fish meal	----	----	----	----	----	----	----	----	6	6	4	4	----	----
Casein	----	----	----	----	3	3	3	3	----	----	----	----	----	----
Desmodium meal[2]	10	10	10	10	----	----	----	----	5	5	5	5	----	----
Kikuyu meal[3]	----	----	----	----	----	----	----	----	----	----	----	----	5	5
Wheat bran	10	10	----	----	----	----	----	----	----	----	----	----	----	----
Ground corn	10	----	20	----	37.5	----	42.5	----	47.5	----	43.5	----	30.5	----
Cassava meal	----	10	----	20	----	37.5	----	42.5	----	47.5	----	43.5	----	30.5
Salt mixture[4]	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Vita-Rich[5]	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.8
A.P.F.[6]	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7
Number of chicks														
at start	24	24	22	22	22	22	24	24	24	24	24	24	47	47
at end	23	24	22	22	22	19	24	24	24	24	23	24	47	46
Average weight (grams)														
at start	41	41	41	41	38	38	38	38	42	42	42	42	43	43
at end	243	237	273	261	238	272	220	244	393**	325	372**	318	338**	300
Feed efficiency (grams fed to product 1 gram gain)	2.92	2.68	2.66	2.54	2.56	2.62	2.52	2.91	2.30	2.71	2.38	2.80	2.65	2.91

**Significant at 1 percent.
[1]Orbignya cohune and species of the genus Scheelea.
[2]Desmodium intortum.
[3]Pennisetum clandestinum.
[4]Calcium carbonate, 1 percent; bone meal, 1 percent; salt, 1 percent; and trace minerals.
[5]Vitamin concentrate, Thompson Hayward Co.
[6]Vitamin B_{12} and aureomycin feeding supplement, courtesy of Dr. T. H. Jukes and the Lederle Laboratorie.

Source: R. L. Squibb and M. K. Wyld (702)

TABLE 7-3. The Digestibility of Cassava Meal (Percent).

	Poultry (Axelsson) 1937	Poultry (Fangauf) 1960	Cattle DLG - Table 1952	Pigs 1958
Digestibility tests	1	--	2	2
Crude protein	86	75	68(54-83)	75(69-81)
Crude fat	85	60	23(7-39)	60(40-80)
Crude fiber	8	55	76(65-87)	55(47-63)
Nitrogen-free extract	87	99	99(99-99)	99(99-99)

Cource: H. Vogt (805)

the best replacement level was 10% of the diet for animal performance and 18% for most economical feeding.

Cattle:

In a study on milk production (150) cassava meal was used to replace the cereal grain up to 41.5% of the ration. Five treatments were used to evaluate 0 to 41.5% cassava meal in the diet. There was a linear decrease in milk production with each higher level of cassava meal used in the diet (7.78 kg down to 7.34 kg of milk per day). However, net income was highest with the highest level of cassava in the diet and lowest in treatment 5 where no cassava meal was used.

A trial was conducted with dairy cattle in Costa Rica (526) to evaluate the value of cassava leaf meal in replacement of alfalfa meal. A double reverse experimental procedure was used and each cow served as her own control. The results were that milk production increased when alfalfa was fed and production decreased consistently when they were given cassava leaf meal. While the difference was statistically significant, the authors stated the production was 90 to 96% of the production with alfalfa; therefore, it was concluded that the leaf meal was a valuable feeding product. There were no disturbances in the animals and the cassava leaf meal was an economical replacement for alfalfa meal.

There are only a few research reports available pertaining to the use of cassava in cattle finishing trials, and the number of animals per test have been limited also. However, the results are good and there appears to be real potential for the increased use of cassava in cattle rations in tropical areas. In one experiment, cattle fed on

a diet with cassava as 75% of the diet gained as fast or faster than four other treatments (533). Good gains were achieved with cassava and cottonseed meal in a study in Brazil (61).

Holstein male calves gained at the rate of 1.32 kg per day when cassava was included at level of 24% of the diet (136). In another study at the same station (INCAP), wheat and cassava were used as the main sources of energy. Molasses was constant in all four diets at 15% of the diet. Cottonseed meal and urea were compared when nitrogen was held constant. The best gains were achieved when the cassava level was high (up to 37.7%) and urea was used as a part of the protein source. The daily gains were in the order of 1.32 kg on 150 to 200 kg calves. Feed efficiency ranged between 2.3 and 3.0 per unit of gain, which is a reasonably good rate of conversion by lighter weight calves.

DISCUSSION

There is adequate evidence to conclude that cassava can be used in diets for practically all species and classes of livestock. The root is nearly odorless and the taste is very bland or tasteless; therefore, palatability is not a serious problem in animal feeding. However, the optimum level or maximum level for each species and production objectives is not so clear. Some authors stated feed consumption and body weight gain will be increased with some cassava in the diet, but most authors indicated that cassava should not be the only source of energy in the diets. Optimum animal performance has been achieved with diets containing corn, wheat, rice or other high energy grains along with cassava. Specific recommendations pertaining to the optimum level of cassava have ranged between 10 and 50% of the diet. Research with

growing rats is in agreement and within this range. Jeffers and Haynes (391) reported cassava, sweet potatoes and yams differed little from each other and produced satisfactory growth and performance of rats at levels up to 20% of the diet.

The optimum level of cassava for best animal performance was not always the optimum level for the most economical production. Cereal grain supply is deficient in many areas of the world and the price is high. In these cases, while animal performance may be slightly inferior with cassava to those receiving better diets, the use of more cassava in the diet was more practical and economical.

The reasons cassava cannot be utilized as the only energy source have not been explained. The scientific research, especially earlier research, should not be used to conclude that cassava cannot be the only energy source. Many diets were formulated with local available ingredients for the purpose of determining production level with these ingredients. Chemical composition of ingredients was not always known, which made it difficult to balance the diet. For example, no experiments have been reported on adding methionine to the diet. Methionine is very limited in both the root and leaves. Furthermore, methionine is one of the most limiting amino acids in soybean and cottonseed meals.

A high level of HCN in cassava could possibly have been involved and caused poor growth rate when a high level of cassava was used in some studies. Certainly, more research on toxicity effects on animals is needed.

Maner (486) indicated a palatability problem at the time of starting young pigs on experiment, but consumption increased to a

satisfactory level later in the test. At the beginning, the pigs were hungry and preferred the protein supplement to meet their energy requirement. Perhaps taste, odor, texture and other factors were contributing to their preference of feeds. Dried cassava can be ground too fine for animals. Fine materials mat on the beaks of chickens and they become pasty in the mouth of pigs. Cattle do not care for fine dusty feeds.

The problems associated with the use of a high level of cassava in animals' diets is recognized and cannot be ignored, but some animals probably can use cassava efficiently as the only source of energy. Detailed research will be necessary in the broad catagories of feed preparation, ration palatability, and protein, lipid, mineral and vitamin nutrition to accomplish this goal.

Cassava silage has excellent potential as a livestock feed. The serious limitations to cassava as a feed for livestock are the problems of storing raw cassava and the cost of drying. If silage were fed the raw cassava could be harvested and stored for several months. The silage could be the roots alone or the roots and leaves. Some form of dry matter mixed in with the silage may be beneficial to increase the energy content and decrease the loss of nutrients by lowering the liquid drainage. High nutrient losses have been reported with excessive loss of water after ensiling certain feeds with a high concentration of moisture.

Cassava leaf meal is apparently nearly equivalent to alfalfa meal in nutrient content and feeding value. The dried product is a good source of protein, fiber, minerals and vitamins. The leaves and tender stems can be included in silage or fed green or dried to cattle, swine

or poultry. The cost of preparing cassava has not been studied in detail. Another major problem with use of cassava for feed is the harvesting. Reasonable mechanical ways of harvesting the leaves and roots should be developed.

Relatively high tonnage of foliage can be produced per hectare. The root:shoot ratio is about 50:50 and extensive foliage develops prior to the growth of roots (759). If 60% of the plant could be used as cassava leaf meal, one might attempt to predict yields. Yields of roots vary dramatically and the same is true of leaves. The world average production rate is estimated as 7-9 metric tons per hectare (295). A common yield in Cali, Colombia, is 40 tons per hectare (486). If 24 tons of foliage could be harvested per hectare, it would be a good source of nutrients. Normanha (545) cut two crops of foliage and harvested 6 and 4 tons/ha and still produced within 30% of the normal yield of roots. However, two years were necessary to harvest two crops of foliage.

The economic advantage of using cassava in livestock feeds in place of other grains is not well documented. A few authors have stated an advantage (see animal experiments), but the exact economic advantages are obscure. Of course, the change in supply and demand of crops and animals causes changes in net profits which makes any conclusion about profit nearly impossible. Nevertheless, with the assistance of Dr. Maner (486), an attempt was made to compare the economics of cassava or corn in swine diets in Cali, Colombia.

The prices used were: corn - $92.50 per ton, soybean meal - $125.00 per ton, cassava - $15.00 per ton fresh or $50.00 per ton dried (included drying cost). The price of a corn-soybean meal type diet was calculated

to be 10 cents per kg, whereas the price of a similar diet with cassava was 7.75 cents per kg. If a feed efficiency of 4.0 (3.2 is good) is used and a price of 61.5 cents per kg of animal weight is used, the profit above feed cost is calculated to be 21.5 cents per kg with the corn diet and 28.0 cents per kg of body weight with the cassava diet. If an advantage were given to the corn diet for better feed utilization, the cassava diet would still be more economical.

The average yield of corn in Cali is 2.5 tons per hectare and 6 tons have been produced on experimental plots (486). Two crops per year yield up to 12 tons of 90% dry matter per year. Cassava yields of about 40 tons and 78 tons have been harvested per hectare in one experimental plot. Thus, dry matter (DM) production per hectare for the following yields would be:

Yield (tons)	DM/ha/year (tons)
30	10
40	13.3
50	16.5
60	20.0
78	26.0

The average yields of DM with cassava was better than experimental yields with corn. The figures could be far more impressive if values from areas of poor soil quality or more tropical areas where corn and other grains will not grow well were used.

CONCLUSIONS

Limitations and Problems of Cassava as an Animal Feed:

a. The balance of nutrients is not equivalent to cereal grains, therefore, more proteins, minerals and vitamins from other

sources must be included in diets. This can be achieved, but more protein feeds must be grown or shipped to the feed manufacturer.

b. HCN in certain plants can be high, yet the toxic material can be released by proper treatment.

c. Storage of cassava is a problem. Deterioration of the root will occur within a few days after harvesting. The roots can be dried and stored or silage could be made for certain animal diets. While storage is a problem, the root does not need to be harvested at maturity and the plant can be left undisturbed without extensive nutrient loss.

d. Mechanical methods of harvesting would be necessary for large acreages and high animal production. These techniques have not been developed and equipment is not available.

Advantages and Potential of Cassava in Livestock Feeding:

a. The primary advantage is the high yields of calories on poor soils and in areas where grains will not grow or yield is relatively lower.

b. The roots and leaves can be used for human food and animal feed.

c. The cassava roots, leaves and by-products of starch manufacture can be fed to all species of livestock.

d. Silage or dried materials can be utilized by animals.

e. Inedible products can be converted into edible products for human consumption

f. Higher farm income can be realized by farmers in the tropics and agribusiness can be improved.

g. Animal protein and other nutrients and animal by-products can be increased for human use. One preliminary experiment was used

to show a potential of the synthesis of protein by fungi and cassava. Nearly 15 grams of additional protein per pound was produced (346). The use of nonprotein nitrogen such as urea with cassava in cattle rations is another way of increasing the production of valuable amino acids. W. O. Jones (409), in his book Manioc in Africa, stated it well when he said, "perhaps the most promising way to take advantage of the low cost and great productivity of manioc is by feeding it to livestock."

RECOMMENDATIONS

Possibly the greatest potential of cassava utilization is through increased feeding and production of livestock. Cassava is not equal to cereal grains in nutrient content, yet it has a unique place by having high yields and good growth potentials in areas where poor soils and adverse climatic conditions limit the production of cereal grains. Therefore, cassava can be used as an animal feed to make a significant contribution to the energy and protein needs of the human race.

a. A research program should be established to conduct extensive detailed experiments with swine, poultry, cattle and laboratory animals. The research should be conducted at one or two research centers in areas of cassava production. If centers cannot be established the research at existing centers throughout the tropical areas should be coordinated as much as possible.

b. From the standpoint of animal feeding, plant breeding experiments are needed to develop higher yielding varieties with more nutrients. Emphasis should be placed on improving the protein level and protein

quality. Varieties should be selected for ease of harvesting and maximum foliage production without sacrificing yield in roots. A high forage yielding variety without regard of the root might be another possibility.

c. Plant breeders need to develop a good source of protein which can be grown in the tropics. A good source of protein feed will be essential for good utilization of cassava.

d. Agronomists should study the nutrient requirements of the plant and develop maximum yields. Agronomists and animal nutritionists should determine the nutrient content of cassava when grown in various environmental conditions.

e. Good means of mechanically harvesting leaves and roots must be developed. Good methods of handling, storing, drying and automatically feeding will be needed in large livestock enterprises.

CHAPTER VIII

Processing Cassava for Industrial and Food Uses[1]

Cassava is used internally within the various producing countries principally as a fresh crop where it is a major component of the diet in the rural areas and frequently provides the only insurance against famine. Although it is looked upon as a subsistence crop having poor nutritional value, it supplies more calories per hectare of land than any other crop planted in the tropics.

Ordinarily, the roots are dug manually by laborers using hand tools only. To date, no satisfactory plow or digger is in use although Salvado (658) has devised a digger which he claims is satisfactory. After the plants are dug, the roots are cut from the stem ends and the tips trimmed to reduce the amount of soil and woody bark (56, 75, 483).

A large percentage of the cassava that is harvested is dried or otherwise processed (Table 8-1). When the roots are dried to yield chips, the tubers are usually sliced or diced and dried in the sun on concrete slabs heated ordinarily by a wood fire or in a simple drying oven. After drying, these chips may be used to produce a crude cassava flour.

For the most part, the technology of drying the tubers is primitive or rudimentary. There are a few tunnel dryers and cabinet dryers in use but this is the exception rather than the rule. The Instituto de Tecnologia Alimentar (ITA) in Brazil is experimenting with solar energy as a source of heat for drying chips held in a cabinet (518).

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[1]Prepared by John C. Ayres, Department of Food Science, University of Georgia, Athens, Georgia.

TABLE 8-1. Uses of Cassava.

Root

Raw (peeled young root or aipim)
Cooked, boiled, or baked for table use (95% of production)
Shredded and mixed with coconut, oil, peanuts, greens, spices
Dried (called kokonte, gaplek, etc., in Africa)
Grated and fermented, added palm oil, fried (called gari in Africa)
Fried slices (French frying, etc.)
Residue (fiber or bagasse) from starch extractives
Chipped or sliced for livestock (dairy and beef cattle, goats, pigs, chickens)
Root peel livestock feed
Broken roots
Pellets (landang)
Juice (tucupay or cassaripo)

Leaf

Used as a vegetable
Cooked
Soup ingredient
Fortified food supplement
Livestock feed
Ensilage
Dried - Used in animal feed fortification
Leaf meal (feed concentrates)

Stalk (stems)

Cuttings for plant propagation
Grafting material for increased yields
Mixes with leaves as ruminant feed
Dried (used in animal feed concentrate)

Chips (raspa or gaplek)

Ground into meal or flour
Extracted for starch
Fermented (fufu) - meat, oil, vegetables, spices and water added
Animal feeds
Pellets

TABLE 3-1. (continued)

Meal or flour (farinha da raspa)

Bakeries, pastries, alimentary pastes (macaroni)
Boiled in soups, sauces, gravies, etc.
Bread extender
Porridge (gruel)
Fortified flour (with wheat, soya, peanut, vitamins, etc.)
Improved bread flour (with added calcium stearyl lactate as a conditioner)
Protein enriched flour (fish protein concentrate, soybean isolate, casein, etc.)
Selected amino acid enriched flour (lysine, tryptophane, methionine, etc.)
Fermented (Eba)
Glues
Adhesives

Starch

Baked goods
Desserts - puddings, pie fillings (sagu)
Infant foods
Confections (molding of cast candies)
Thickening agents (synthetic jellies)
Bodying agents (caramels)
Dusting agents (chewing gum)
Fermented beverages (beer)
Textile sizing and strengthening
Laundry starch
Paper sizing and bonding
Gums (envelopes, postage stamps, gummed tapes)
Dextrins (bonding pigment to paper; preventing glass cracking)
Adhesives (cardboard, plywood, and veneer)
Glues and pastes
Blended with peanut flour, nonfat milk solids, vitamins
Enriched with FPC, soy, corn, rice (pasta)
Alcohol
Acetone
Glucose
Oil well drilling

Modified starches

Precooked soluble starches - "instant" puddings
Thin - boiling starches (candy manufacture)
Oxidized starches
Improved starches (ex: added glyceryl monostearate as a binding agent)

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hundreds of thousands of family size flour mills are located on farms and in villages throughout the tropics. Often these are wholly or partially enclosed units containing a few crude pieces of machinery and other equipment such as a cylindrical or U-shaped washer, a motor-driven rasper, a hand-operated screw press and a wood-fired oven with a flat-metal plate over which the heated drying meal is raked. It is estimated that, of cassava growers in Brazil processing less than three hectares of cassava, about a fourth own such plants and that most of their neighbors either use the equipment without charge or provide the owner with a certain amount of final product (up to 25%). When the grower has more than 3 hectares planted in cassava, it is generally not profitable for him to operate under barter conditions. Instead, he may own a larger flour mill and hire personnel from nearby to help with peeling, washing, macerating, pressing, gelatinizing, drying and bagging the meal or sell it to an operator who will handle the product.

In even the largest flour mills, a great proportion of the work is performed manually. The machinery in these processing plants if often hand operated (as the filter press shown in Figure 8-1) or driven by a small power motor (as the rasper shown in Figure 8-2). These two units are capable of handling 300 kg (filter press) and 800 kg per hour (rasper) respectively. A power driven rasper capable of macerating 1,500 kg of roots per hour (Figure 8-3) and a small power driven uniformizing (grinding) machine (Figure 8-4) capable of handling 300 kg of product per hour are additional pieces of equipment that may be found in larger flour factories.

Cassava meal or the gari of Africa is prepared in much the same way as farinha de mandioca in Brazil, except that the root is reduced

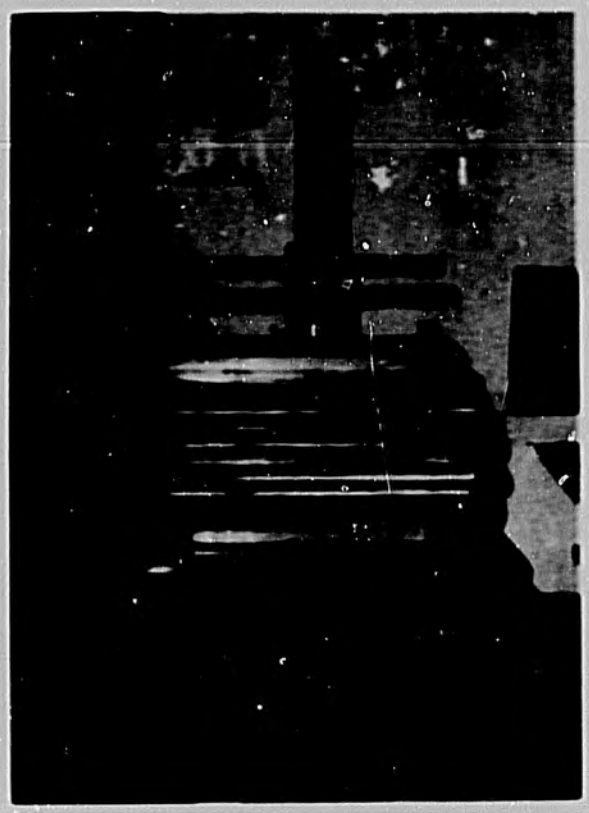


FIG. 8-1. Hand operator filter for pressing fruit water from macerated roots. This filter is capable of pressing 300 kg per hour. Manufactured in Pernambuco, Brazil. Cost U.S. $100.

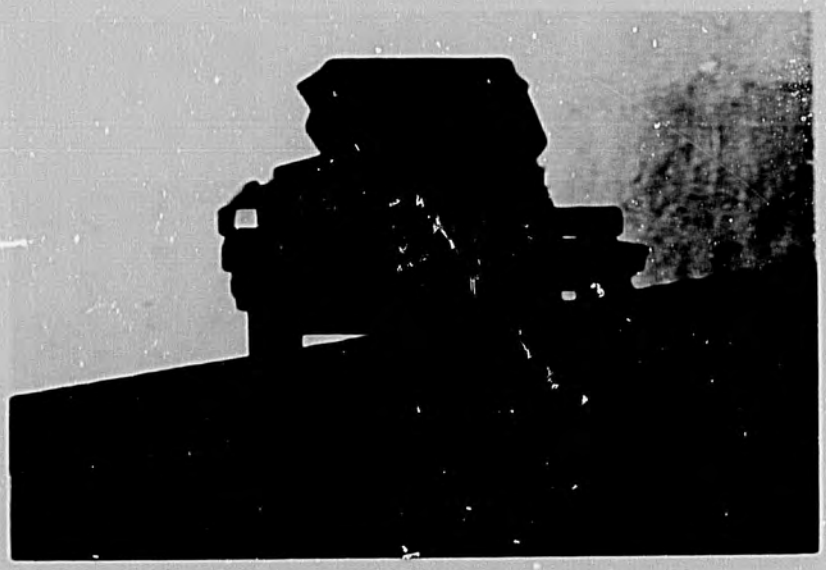


FIG. 8-2. Power driven rasper with hand operated "feeding block". This machine has a capacity of 800 kg per hour. Manufactured in Pernambuco, Brazil. Cost U.S. $60.

FIG. 8-3. Large motorized rasper and two power driven feeding blocks. This machine macerates 1500 kg of roots per hour. A vibrating table is often added to catch the rasped roots from the trough (lower left). Manufactured in Pernambuco, Brazil. Cost U.S. $300.

FIG. 8-4. Motor driven Uniformizer (grinder). This machine handles 300 kg per hour. Manufactured in Pernambuco, Brazil. Cost U.S. $100.

to pulp by hand grating and the water is squeezed from bags containing grated cassava with the help of heavy stones or logs. The pulp that is allowed to sour and ferment for several days before it is removed from the sack receives a final drying in a bowl held over a low fire.

In contrast to the simplicity of equipment and operations for producing cassava chips or meal (farinha de mandioca and gari) the technology of starch production is quite advanced and requires sophisticated machinery (the production of starch will be described in detail later).

TOXICITY OF CASSAVA

Two so-called cultivars of cassava are recognized: bitter and sweet. Some distinction must be made between these two types. Sweet cassava is grown for table use while the bitter type, which has a higher starch content, is cultivated for industrial purposes. Bitterness has been associated with glucoside content, however, there is no reliable morphological procedure to characterize plants that have a certain glucoside content (105, 119, 120, 123, 300, 543, 544 569, 583, 590, 591).

Godoy (327) observed that raw roots of a sweet variety grown in one region can become bitter under different conditions of climate and altitude. Others have shown (409) that the prussic acid content varies markedly with growing conditions, soil, moisture, temperature and age of the plant.

A cyanogenetic glucoside, B-d-glucoside, manihotoxine or phaseolunatin (linamarin), as well as some hydrocyanic acid in the free state is associated with the milky sap of the cassava plant (181). When the plant is cut or bruised, this sap, or latex, exudes from small sacs

located just beneath the peel or bark. Linamarin undergoes hydrolysis, especially in the presence of an enzyme linase, to yield free hydrocyanic acid (HCN or prussic acid) and glucose so that the amount present in the plants may vary from harmless residues to lethal amounts (838, 839). Hydrolysis can be accelerated by soaking the roots in water or by heating but, if the temperature exceeds 75°C, the enzyme linase is destroyed (409).

Cassava cultivars are usually considered sweet if they contain less than 50 milligrams of prussic acid per kilogram of flesh (fresh weight). Those having more than 100 milligrams of prussic acid per kilogram are considered too poisonous (bitter) to be eaten; yet pure starch may be extracted from them (119). Greenstreet and Lambourne (347) believed that the prussic acid content of sweet varieties averaged about 70 milligrams per kilogram, while HCN levels of bitter varieties ranged from 200 to 300 milligrams per kilogram. The smallest dose of HCN known to have been fatal to an adult is 0.06 gm, but recovery has taken place after 0.16 gm has been ingested (535).

Where the cultivars used are known to have little, if any, of the cyanoglucoside, the tubers are occasionally peeled and eaten raw. More commonly, the roots are consumed after roasting or boiling. The peeled tubers may also be sliced, frozen, made into paste or ground and dried and used as pellets, meal or flour. During washing and drying, most of the hydrocyanic acid disappears.

INDUSTRIAL USES

The starch of the cassava root is a white granular carbohydrate that is synthesized within the plant by combination or polymerization

of a large number of glucose molecules and serves as a reserve food supply during dormant or slow growing seasons to meet the metabolic demands of the plant. When treated with acid or by certain enzymes, it is hydrolyzed into its constituent glucose molecules. In a similar manner, the digestive processes of man and animals regenerate glucose from starch. Superficially, the fine particles all look alike, but when viewed microscopically, it can be seen that the granules are composed of various round, truncated egg-shaped, and cap-shaped cells whose size and shape identify their botanical source. Not only are the starch molecules arranged in the orderly pattern of a spherocrystal, but when viewed under polarized light, each granule shows a characteristic dark cross pattern (835).

Starch is a polymer of glucose in which these units are combined principally through 1, 4 glucosidic linkages. The starch granules are made up primarily of two types of carbohydrates: amylose, a straight chained polymerized maltose, and amylopectin, a branched chained polymerized maltose. Since cassava starch consists of only 17 percent amylose and the remainder amylopectin fractions, as contrasted to 22 percent amylose for potato starch and 27 percent for corn starch, it possesses unusual viscosity characteristics. As with all the common starches, the amylose and amylopectin fractions are extremely large (with molecular weights in 6 or 7 figures according to Radley (615)) when compared with their constituent glucoses (180 M.W.) and therefore, are effective film formers. In addition, the large percentage of branched chained amylopectins of cassava starch gives it great dimensional strength so that it is difficult to tear apart. As a consequence,

when it is used to size the surface of paper or to size cotton, worsted or spun rayon warps, the starch gives great tensile strength to the paper or textiles. Starch tightly binds loose fibers to the surface of threads and strengthens the warps to resist abrasion and breakage during weaving and improves the feel of the cloth

Cassava starch imports by the United States reached the high level of 196.9 million kg in 1937 compared with 311.4 million kg of corn starch sold that year. However, in 1961, starch produced from corn in the U. S. amounted to 989.5 million kg (771). Most of the cassava starch used in the U. S. prior to World War II was imported from Indonesia but in 1941 these imports were cut off. The potato starch industry was able to partially replace the unavailable root and tuber starches by furnishing a sufficient supply of starch for essential uses. Importation of cassava starch resumed following World War II. Presently, Thailand and Brazil are the principal suppliers but the quantity has been below 90,000 metric tons in recent years (777). This tonnage is approximately equal to the American production of potato starch in 1960-61 and is enough to furnish strong competition for both corn and potato starch, particularly in paper sizing (766).

Industrial Starch:

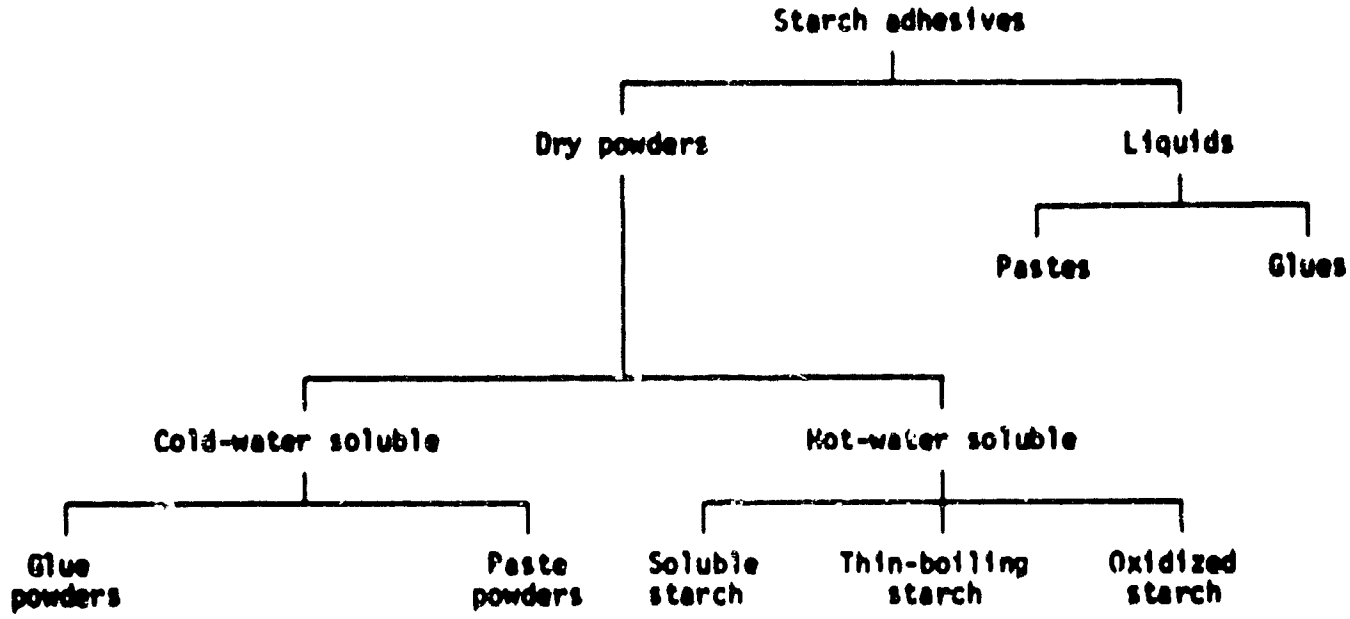
There are a few large processing plants in Thailand that have centrifugal separators and other sanitary machinery that enable them to manufacture high grade cassava starch. For the most part, starch production in that country is of industrial rather than food grade. In Latin America, industrial cassava starch is the principal starch used for adhesives as well as for surface sizing applications. When the

starch is of good quality, it is superior to most other starches as an adhesive raw material. Fluid, stable glues of neutral pH that are miscible with a wide range of synthetic resin emulsions, are easily made from it. Cassava starches are easily transformed into transparent and fluid adhesives at room temperature (Figure 8-5). Cassava glues range in solids content from 10-28%. Such glues provide good bonding of foil to paperboard in the preparation of laminated foil-paperboard. In many respects, cassava starch is similar to waxy starches but the latter redisperse in water more readily (260)

For surface sizing applications, corn starch is the major product used, but cassava, potato and wheat starches are widely used in areas where these starches are readily available and procurement is economically favorable.

Cassava starch provides good parent material from which to hydrolyze dextrins. Evans and Wurzburg (282) indicate that dextrins are much more soluble and more readily formulated in adhesives and that the resulting adhesives have much better working properties than those made with native starch. This permits them to be used in applications requiring partially or totally soluble binders. Products such as gums for envelopes, bottle labelling adhesives, adhesives for remoisturing gummed tape, postage stamps, and lined cardboard boxes are a few of the applications of dextrins. High viscosity dextrins are also used in binding pigments such as clay to paper in the paper coating process and in the glass fiber industry to form a film which acts as a sheath for the fiber to protect it against abrasion. Films of dextrins made from root and tuber starches such as cassava, sweet potato and potato have

FIG. 8-5. Classification of Starch Adhesives.



Source: E. F. W. Dux (260)

been found to have greater flexibility and resistance to checking than dextrins from cereal starches. It has been observed that cassava dextrins have less tendency to become brittle at low humidities.

Home Factories:

In Thailand, home industries comprise the basis for most industrial-grade starch production. Except for a gasoline motor or a water wheel, manual labor accounts for the principal source of power. The roots are washed and peeled in a slotted revolving drum into which water is sprayed. As the drum revolves, the abrasive action causes the roots to be partially peeled. Then they fall onto a short wooden log, about a foot in diameter, that has many sharp metal nails projecting a few millimeters from its revolving surface. A stationary wooden plate with sharp, multi-rowed comb-like metal teeth is placed so that as the log rotates, the roots are torn apart to form a coarse pulp. The macerated root pulp is mixed with raw (untreated stream) water and placed in a wooden tub or cement tank for a day or so to allow the cells to partially disintegrate and release additional starch. The fermented pulp is poured onto a thin, gauze-like cloth which is shaken while water is sprayed onto the macerated root pulp, washing the starch milk into a wooden tub or cement tank. The starch solution -- and some of the fiber -- is allowed to settle, but the coarse waste pulp that collects on the shaking cloth is discarded to be used for animal feed. The pulp may be spread out and allowed to dry in the sun or it may be dried and toasted in heated pans.

After the starch has been allowed to settle, the surface water is carefully poured off so as not to disturb the sedimented starch and fresh water added while the starch cake is broken apart with wooden

paddles and again allowed to settle. After the liquid has been decanted from the resettled starch, the remaining fresh water is sponged from the starch sediment. Then the cake is removed from the settling tank, crumbled and placed on bamboo mats. Ordinarily, the cake is sun dried, but in some of the larger operations, the caked starch is spread onto a large heated cement surface. The starch may be pulverized and new surfaces exposed by pulling wooden rakes or rollers through or over the surface. The final product is characterized as having a sour odor, low pH, high bacterial count, low viscosity, high fiber and ash, and an off-white color with many dark specks and other impurities (671). Often, dealers buy and collect materials from many small producers and, in turn, grind, screen, and blend these together to up-grade and uniformize the final quality.

Owing to the rather unsavory conditions by which the product is made, it is not desirable for food usage. However, it is quite satisfactory for textile sizing and in the manufacture of corrugated paperboard. The largest quantities of cassava imported into the United States from Thailand and the Far East goes into such usage.

Partially Mechanized Processing Plants:

The typical cassava processing "factory" in Southern Brazil is more mechanized than its far eastern or African counterparts (162), but again is a small operation that employs only a few adults and sometimes several children (as peelers). Generally, it has a small supply of equipment consisting of a washer, occasionally a peeler, a mechanical shredder, screw press, settling tanks, and drying oven.

The factory is usually surrounded by several small plots of land upon which cassava is growing. The mean size of these plots varies from 0.5 to 10 hectares and seldom exceeds 100 hectares. Harvest of the crop may begin within about six months after planting, but generally for dried chips, pellets, flour, or starch the roots are at least a year old or more. The unwashed tubers are received at the processing plant by wagon, cart or basket and, if sorted, are separated according to size and condition (i.e , whole roots, broken pieces, amount of debris, soil, etc.) and then washed.

Except for plants where tubers are cleaned and peeled manually, washing takes place by mechanical abrasion in a U-shaped slotted trough with paddle arms or in long perforated cylinders mounted at a slight angle and with a central perforated pipe carrying water throughout the length of the cylinder. The cassava roots are fed from a hopper into the upper end of the washer and as the cylinder revolves, the tubers are cleaned by rubbing against each other and with the sides of the cylinder so that by the time they reach the lower end, much of the soil and peel have been removed. When most of the thin outer peel has been rubbed off or cut off, the tubers are then shredded or rasped by macerating them between a rotating drum and stationary plate fitted with sharp metal blades that shear the material as it is held by centrifugal force against the blades. The rasp reduces the roots to a fine pulp which, in turn, is washed free from the rasper so that it passes through a slotted screen to a hopper at the bottom of the drum.

The slurry of pasty material is strained through frames to which canvas has been tacked. The free starch passes through the screen and

collects in large cement tanks where it settles to the bottom. The coarse fibrous material that is retained on the screens or canvas frames is placed in a screw press and the remaining liquid is forced through the filters under pressure. Fresh water is sometimes added to the filter presses to extract the last remaining amounts of starchy liquid from the fibrous debris. After releasing the pressure on the screw press, the fibrous material is removed from the filter frames, collected, and sold as feed for pigs and cattle.

The starch that has been collected in the cement tanks is freed of excess water by siphoning off the lighter liquid or by unplugging a series of drainage holes that have been placed beforehand in the tanks at varying heights. When the tank is drained of most free water the rest is removed using a squeegee and cloths. The remaining starch sediment has an almost solid consistency and is shovelled or pushed from the tank into a secondary vessel where it may again be stirred to a homogeneous slurry with any of various paddles or other stirring devices and again allowed to settle overnight and the supernatent liquid again discharged. The block of wet starch that remains is then broken into small pieces. This moist crumbled starch is rubbed through a 20-mesh screen and spread on canvas covered trays placed in racks and moved to a drying house -- a heated building with vents to allow the moisture to escape by convection. In addition, some plants pull or push air through the starch with the aid of fans. Often, smaller plants do not mill the starch but instead partially gelatinize it by heating in shallow iron pans or over an iron plate where it is moved rapidly from side to side so that the granules agglomerate and do not burn. The

material that derives from this operation is in the form of hard translucent pellets or irregular shaped globules referred to as "tapioca pearls". Generally, the tapioca is again sieved through a 20-mesh screen and then dried. After the dust has been aspirated or separated by winnowing, the remaining fines (or grist) are removed from the larger pellets. The grist is referred to as tapioca "seeds" and the still smaller particles are considered to be tapioca "flour".

The quality of the starch varies from plant to plant. Some processors exercise great care and consistently produce a clean, white starch that is satisfactory for use in foods; the products of mills having less rigid standards are adequate for use in paper and adhesive manufacture.

Most modern tapioca starch manufacturing plants use fresh cassava roots. However, a good quality starch has been made in some of the potato starch plants in Europe using peeled, dried cassava roots imported from Africa. This process is much more difficult to control and is very costly when compared with the use of fresh roots (67).

Food Starch.

Tapioca has a bland flavor and forms a clear but long cohesive paste. When used for foods, tapioca starch is found primarily in chemically modified products in the form of partially gelatinized pellets or "pearls". It has the lowest temperature of gelatinization of any of the commonly used starches. With tapioca, gelatinization begins at 52°C, reaches a mid-point at 59°C and terminates at 64°C (Table 8-2).

TABLE B-2. Gelatinization Ranges of Several Food Starches.

	Temperature at loss of birefringence (°C)		
	Initiation	Mid-point	Termination
Corn	62	66	70
Rice	68	74.5	78
Wheat	59.5	62.5	64
Potato	58	62	66
Tapioca	52	59	64

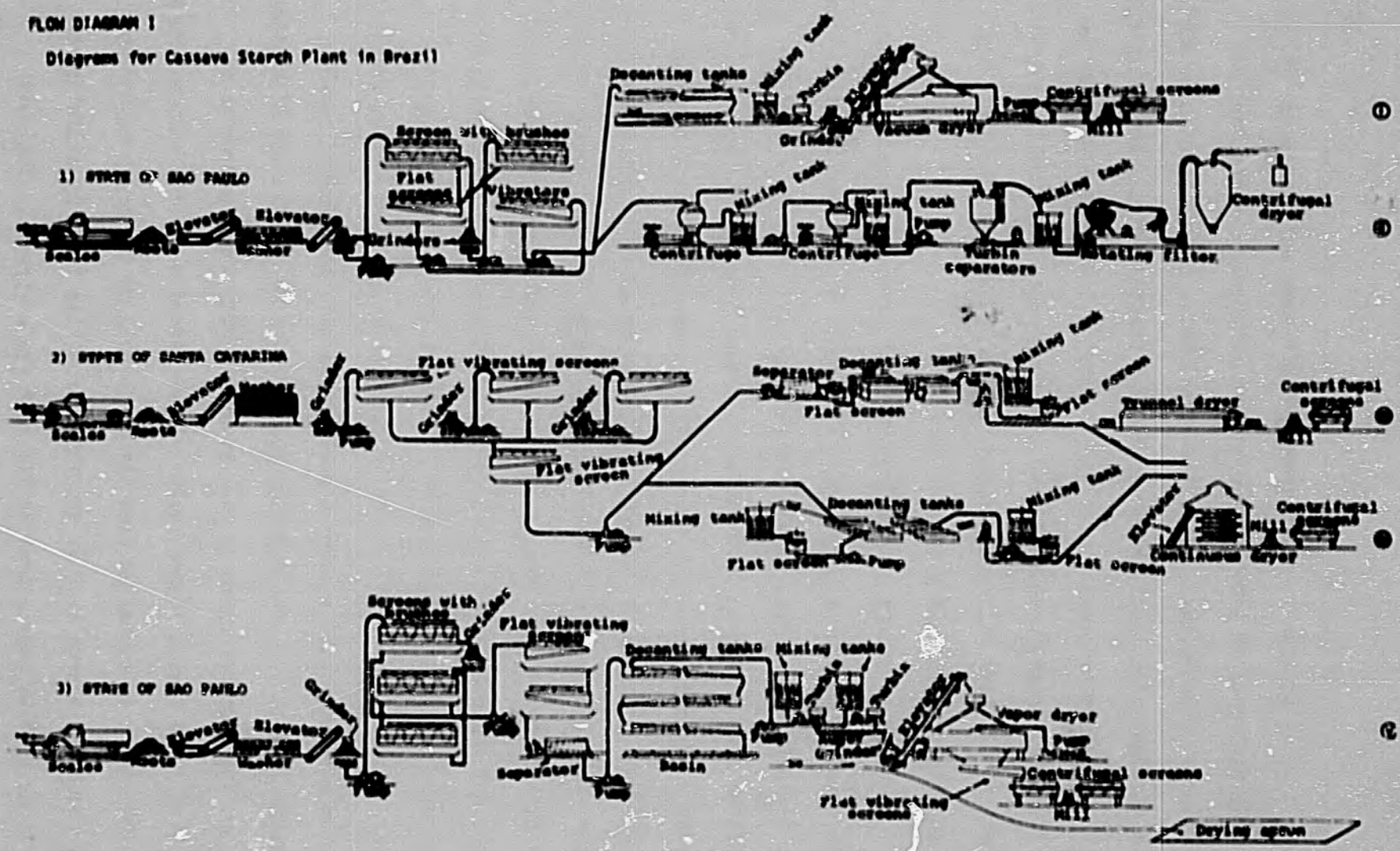
Source: E. M. Osman (after Schoch) (562)

In order to obtain starch free from off-odor and discoloration, freshly dug roots of known starch content, properly cleaned, peeled and macerated using pure, soft (iron-free) water and sanitary equipment, good manufacturing practices through all processing steps, and efficient drying and storage are all necessary. Several plants in South America fulfill these requirements and are able to produce high quality starch. Modern plants have been established in Southern Brazil (Sao Paulo and Santa Catarina) (see Flow Diagram 8-1).

In order to assure a satisfactory final product, these plants adhere to the following modus operandi: roots are brought directly from the field to the plants, washed and peeled by abrasion in a slotted rotating drum having an internal water spray. Roots with too much peel, broken roots and those with woody ends or other defects are removed, trimmed and returned to the peeler. Sound peeled roots are ground in hammer mills equipped with metal screens having 3.5 mm diameter holes. The pulp is mixed with fresh pure soft water and pumped to a series of vibrating screens fitted with 50-60 bronze gauze or to brush washers. Some plants have six-sided screens for separating starch and coarse fiber. A water spray is used on the screens to keep the meshes clear as the screens rotate. Other installations have more modern brush washers. These are long troughs equipped with an angular set of brushes resembling a spiral conveyor that moves the pulp along and works it against perforated U-shaped copper plates fitted along the bottom. Much of the starch is extracted from the crude pulp by the brush washer and the resulting starch milk is separated from fine fiber by allowing the solution to flow over vibrating 120-mesh gauze screens. The pulp

FLOW DIAGRAM I

Diagrams for Cassava Starch Plant in Brazil



discharged from the first brush washer is reground in a second hammer mill in which the retaining screens have 1 mm holes. The pulp is pumped to a second brush washer and the starch milk passes to a vibrating screen while the spent pulp is discharged from the factory as waste or to a pulp drying section in the plant. The vibrating screen produces starch milk which is pumped to a second set of vibrating screens fitted with 200-mesh bronze gauze. Just before this final screening, a 0.2% sulfur dioxide (SO_2) solution is added at the rate of 0.5 liter/kg of dry starch. The SO_2 solution improves the color of the starch, hastens settling and prevents microbial deterioration. The pulp remaining on the vibrating screens is sent to the waste effluent or added to the first screened pulp and dried. The starch may be washed and concentrated in a centrifuge or sent directly to settling tables. The starch settles as the liquor flows from table to table. Twice daily the tables are freed of all residual fiber and fines by a jet of high pressure water. Starch from the tables is washed several times in tile-lined tanks and the water content reduced to 35-38% by centrifuging. The impurities and discolored starch remaining at the core of the centrifuge cake is scraped away and the remaining starch crumbled and sent to steam heated vacuum drums. Some gelatinization is inevitable and this "cooked" starch is removed by vibrating and/or centrifugal sifters. Finally, the starch is bagged in sanitary multi-wall, valve-type bags (671).

In recent years, several modern plants have been set up in Thailand that are able to consistently produce high-grade starch. These plants are equipped with a complete tapioca starch processing system designed by the Swedish firm of Alfa De Laval. Instead of needing eighteen hours

to obtain the final starch product that the routine tabling settling process requires, the Laval process requires only forty minutes to transform roots into finished starch. The faster process avoids many microbiological, viscosity, pH, odor and color problems.

Shipman (671) described important differences in this procedure and those described earlier as follows: washed, peeled roots are routed through a chopping machine prior to rasping. Then the finely ground pulp is fed into the small end of a vertically revolving, conical refining screen which by centrifugal action forces the starch through the screen while the pulp migrates into the larger portion of the cone and is discharged. These refiners are arranged in two batteries of two or three screens in series so that there is a second rasping of pulp between the batteries. Nozzle centrifuge-separators remove "fruit water" (i.e., root juice containing enzymes) and fiber at the same time provides a preliminary washing of the starch. The starch milk is introduced into specially designed separators, entering the base of the rapidly revolving bowl traveling at a speed of 3,500-5,100 rpm. Around the periphery of the bowl are a series of nozzles of different diameters. Fresh wash water is pumped into the bowl through the central spindle and the washed, concentrated starch (11-12° Baume) is forced through the nozzles to the next processing step while the fruit water and fiber are discharged from the top of the centrifuge-separator. The liquid effluent is discharged as waste or reused as a preliminary root wash. The starch milk is treated with sulfur dioxide solution and diluted to 8° Baume before routing to a vibrating screen (120-150 mesh) for the removal of fine fiber. After screening, the starch milk receives a

second centrifugal washing similar to the first which concentrates it to 19° Baume and a final refining in a "purifying" centrifuge, a batch machine that goes through the following cycle: filling, removal of grey starch, reslurrying, washing, reslurrying, and discharge of heavy slurry (18-20° Baume). The starch is dewatered using dehydrating centrifuges lined with canvas cloth that complete a cycle consisting of filling, spinning, cutting out, and discharging dewatered starch having a moisture content of 35-37% in 14-16 minutes. Final drying to 12% moisture is completed using a flash dryer wherein air at high velocity is passed through a heat exchanger to raise the temperature to 150-160°C. Starch is drawn through an air bath and, in a very short time (seconds), the excess moisture is "flashed" off. The dry starch (10-12% moisture) is air cooled and sent to a final cyclone dryer and coarse particles are filtered out with 14 XX mesh silk or nylon screens and then delivered to a bagging machine.

Uses:

Tapioca starches have excellent thickening properties and so are ideal for puddings and pie fillings. The starch may be pre-gelatinized and used in "instant" puddings. The dry formulation of instant pudding is principally soluble starch, sugar and flavoring. The starch dissolves quickly upon the addition of cold liquid (e.g., milk) and then sets to a gelled pudding. Tapioca also has many uses in the confectionery industry. It may act as a medium for molding cast candies such as gum drops and jelly beans, as a bodying agent to provide stability and smoothness to caramels, as a thickening agent for synthetic jellies or as a dusting agent for chewing gums.

Thin boiling starch is used as an ingredient in candy manufacture.

Starch plays a vital role in determining the texture of many foods. Osman and Cummisford (563) observed that the viscosity characteristics are altered by heat-moisture treatment (Table 8-3). Heat-moisture treatment raised the hot viscosity of tapioca but not that of other starches. While heating in the presence of moisture was insufficient to cause changes in gelatinization, it did result in marked changes in the properties of tapioca.

OPERATING DIFFICULTIES

Flour:

Most plant operators appeared to have little knowledge of the causes of spoilage. Often the water used for washing the roots contained metal impurities that caused the meal to be discolored. In some plants, large piles of peels were allowed to remain in the peeling rooms for long periods of time where they attracted insects and rodents and developed foul odors. Fragments of roots were often allowed to remain in the corners of troughs and the housing of rasping drums and, when the equipment was not cleaned regularly, developed putrid odors. Occasionally, press cloths were used again and again without rinsing or replacing. Also, in some plants, the ash from the ovens was permitted to blow into the drying product resulting in discoloration and grittiness of the product. When drying techniques and/or storage conditions were unsatisfactory, the meal picked up moisture and developed musty odors. Good products were obtained only when all steps in processing were handled properly.

TABLE 8-3. Viscosities of 4% Pastes Prepared from Starches Heated at 135° for 3 Hours at 100% RH.

	Hot viscosity (cp)		Cold viscosity (cp)	
	Untreated	Treated	Untreated	Treated
Potato	2,300	1,010	4,600	1,786
Tapioca	770	938	2,250	1,827
Corn	429	418	2,240	1,980
Rice	241	224	1,045	691
Wheat	101	96	1,710	1,107

Source: E. M. Osman and P. O. Cummisford (563)

The production of satisfactory chips, flour and starch depends upon good quality control. The water used for washing the roots, rinsing the wet ground pulp, and extracting and rinsing the starch must be available in adequate amounts, clear, potable and free of metallic impurities. The machinery and other equipment should not be subject to rusting and must be easy to clean. The mechanics of operation should be such that the raw material and product are handled quickly so that there is little opportunity for deterioration or spoilage. The final product should be dried well and uniformly so that it has the desired appearance and color, a low bacterial, mold and yeast content, and be free from any sour or offensive odor. In addition, it should be low in moisture (11-13%) and ash (0.2%) have a neutral pH (6.3-6.5) and high viscosity.

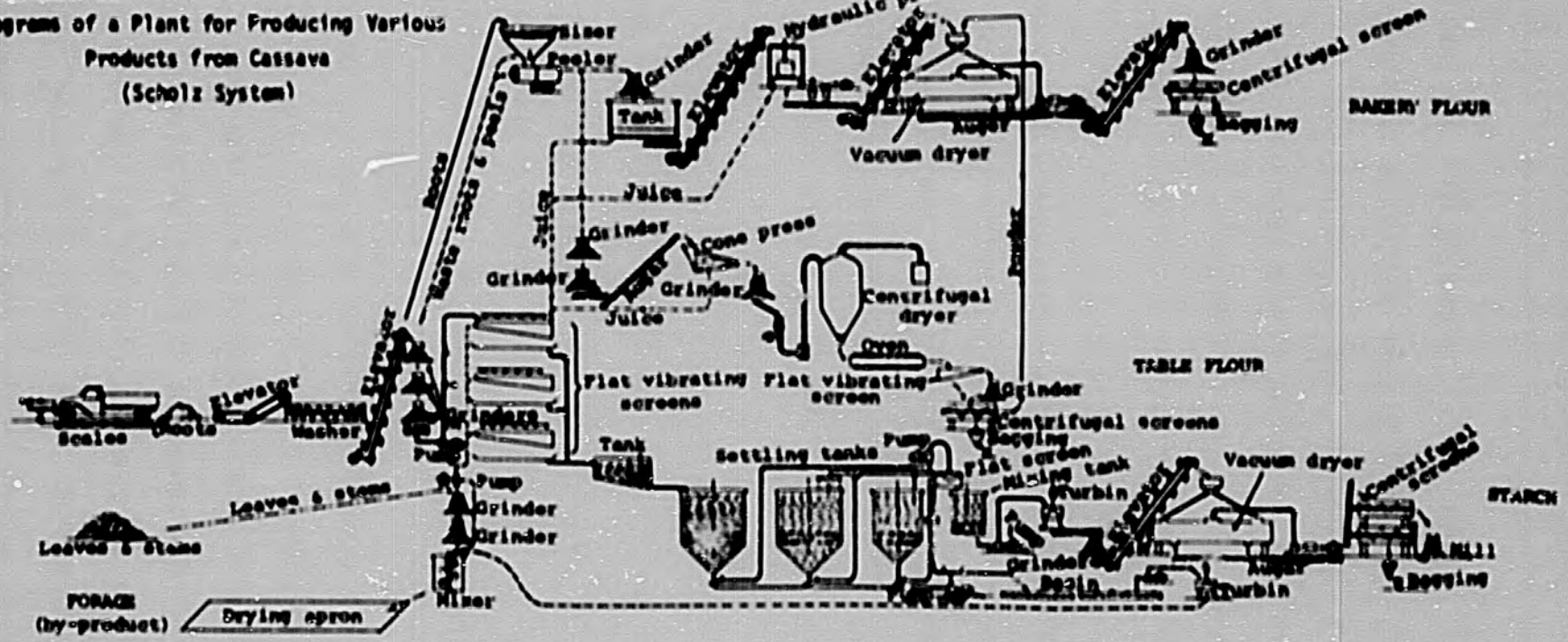
The Banco do Nordeste do Brasil S/A (83) (Mandioca, Aspectos da Cultura e da Indústria) made a detailed study of the processing of cassava flour (see Flow Diagram 8-2). The Bank concluded that many of the smaller plants with primitive machinery were just as successful, if not more so, than some of the larger installations with more modern equipment. Further, they found that failure of plants resulted when (1) the flour plant was improperly located, (2) the water supply was inadequate, (3) a continuous and dependable supply of roots was lacking, (4) the machinery was inefficient, (5) labor was uneconomical, and (6) technical supervision was poor.

Starch:

The world starch industry is based preponderantly upon the starch derived from corn, wheat, or rice, is fiercely competitive and succeeds not from the sale of starch alone but as a result of obtaining maximum

FLOW DIAGRAM II

Diagrams of a Plant for Producing Various Products from Cassava (Scholz System)



numbers and types of other products including by-products. For example, plants manufacturing corn starch produce -- in addition to dry starches -- dextrins, corn syrup, corn syrup solids, dextrose, refined corn oil, corn oil meal, soap stock, corn steep water concentrates, and feeds (69, 418). By comparison, the great majority of cassava processing plants extant throughout the tropics make inefficient use of raw materials, personnel and final products.

In Brazil, very little starch is produced and no large processing plants are actively producing starch in the Northeast at the present time although 40% of Brazilian cassava is produced in that region. Within the past decade, plants were constructed and equipped at Glória do Goitá, Crato, Fortaleza, and Sipe -- the last named at a cost exceeding $600,000 (U.S.). None of these plants was able to produce starch commercially. All lacked the technical skill necessary to satisfactorily extract starch from roots and/or chips. In several, either the planning of the plant or the equipment (or both) was inadequate. An adequate and continuous supply of roots (or chips) and of good water was unavailable for two of the plants. Economic considerations were such that one of the plants did not even open.

In addition to the four inoperative plants visited in N.E. Brazil, the author visited a starch plant near Tipitapi, Nicaragua, having a daily manufacturing capacity of 15 metric tons of starch that was no longer operating because of an undependable supply of raw products. The operator was certain that the plant was efficient and competitive but he did not have sufficient funds to try again. He indicated that the farmers in his area would welcome shifting from cotton to cassava

because the marginal profits that they were receiving from the growing of cotton did not compare with the earnings they might expect from cassava. Yet, if he were to receive funds so that he could operate again, it would still be essential that a planned planting and harvesting program be worked out with his suppliers. Similarly, Rogers (648) has reported that two large processing plants in Brazil and one in Bolivia were abandoned because of lack of water or the presence of iron in the water that was available. The Bolivian plant did not succeed because the local farmers were not able to produce a sufficiently large quantity of roots to make the operation of the plant practical. The cultural practices employed by the farmers were not modified or changed so that the plant could operate on a continuous basis.

As was done for flour, the Banco do Nordeste do Brasil S/A (83) analyzed the operations of starch factories in the south, the central south and the northeast areas of Brazil. As a result of these studies, they observed a number of errors in operations and/or machinery construction and recommended solutions to circumvent these mistakes when planning future installations (see Table 8-4).

CASSAVA ENRICHMENT

Baking:

The use of cassava in the production of bread from nonwheat flour is being actively explored in a number of countries (186, 187, 413). The Instituto de Investigaciones Tecnologicas (IIT) in Bogota has cooperated with the Institute for Cereals, Flour and Bread, T.N.O., Wageningen, the Netherlands, in increasing the properties of nonwheat

TABLE 8-4. Errors in Operations and/or Machinery and Recommended Solutions.

MACHINERY OR OPERATIONS	
ERRORS	RECOMMENDED SOLUTIONS
Washer - drum or wooden basin type	Washer should have non-rusting metallic axles and beaters and the bottom should be of perforated metal. Should make efficient use of water.
Rasper - of small diameter and light weight. Block badly positioned or adjusted for roots. Saws thick and easily rusted.	Large diameter cylinder with heavy grating and reinforced blocks. Blocks adjustable to fit perimeter of rasper. Non-rusting circular saws placed ahead of graters.
Pulp screens - brush screens cause deterioration, loss of starch and are difficult to clean.	Screens should be flat and cleanable with water jets. There should be a second series of finer screens.
Mechanical sedimentation - turbines and separators are expensive to operate and lose starch.	Chemical treatment of starch milk. A series of special sedimentation tanks allows good separation. Water should be renewed twice.
Settling chambers - require much labor and higher maintenance costs.	Automatic decanting with minimal labor gives product with better reproducibility, desired color and viscosity.
Final turbines - (centrifuges) common type is obsolete and requires too much labor.	Automatic discharge types permit self-cleaning and freeing of product impurities.
Drying - temperatures above 50° C cause dextrinization of starch.	Control temperature and ventilation and any type of dryer can be used.
RESIDUE PREPARATION	
A. Washed mass and meal - technique of preparation is expensive.	Mix washed mass with dried, ground cassava stems to facilitate pressing and drying.

TABLE 8-4. (continued)

RESIDUE PREPARATION	
B. Decanting station water - wasted in all Brazilian factories; yet contains the proteins and up to 2% of root starch.	Catch in tanks outside the factory. When added to meals (A), can be used as forage. Flocculate protein by chemical treatments.

Recommendations above are sufficient to provide ideas of improved techniques. There are other errors caused by oxidations or undesired fermentation that should be eliminated.

Source: Banco do Nordeste do Brasil S/A (83)

flour in dough. One of the most difficult problems to overcome from starches that do not contain gluten-forming proteins is that of providing a swelling agent. Jongh (413) tested various substances that would act as a binding agent between the starch granules and reported that glyceryl monostearate (GMS) possessed the desired characteristics. These workers were able to produce a composite flour containing cassava starch and defatted soy flour in the proportion 80:20 when 1% GMS was used as a granule-binding agent. In providing dough from cassava-soy flour it was necessary to add sufficient water to prepare a mixture that had the consistency of a cake batter. The basic recipe for this dough was: composite flour (100 parts of which 80 parts were cassava and 20 were soy flour), compressed yeast (2 parts), salt (2 parts), sugar (4 parts), and water (70 parts).

It was found to be necessary to add the GMS as a 10% emulsion rather than as a powder to avoid unsatisfactory dough crumb structure. Mixing was done with a planetary-type mixer (Hobart Mixer Model N-50) equipped with a batter blade. The mixer was run for 2 minutes at 300 rpm followed by 2 minutes at 600 rpm. The dough temperature was held at 28°C. After mixing, the dough was allowed to have a 40-minute bulk fermentation and then remixed at 600 rpm for 5 minutes. This sponge was weighed into baking pans in 500 gram portions. The dough was proofed at 30°C for sufficient time to give 275 ml CO_2 in 300 g dough and then baked for 30 minutes at 230°C.

With increasing amounts of GMS (from 0, 0.1, 0.5, 1.0, 1.5, and 2.1%), the binding agent was found to provide stepwise improvement of dough stability and loaf volume, texture and softness of crumb (420).

Kim and de Ruiter (420) prepared breads from cassava/soy and cassava/peanut and compared these breads with common Dutch wheat bread. The digestibility of the three breads was 92, 91 and 94, but the biological value and protein efficiency ratio for the cassava/soy bread was 65; considerably better than for the other two which were 54 and 51, respectively.

The addition of cassava flour to wheat flour has an undesirable effect on volume, fermentation activity, and crumb color and texture. Also, breads prepared using cassava flour require much more water than those using cassava starch (i.e., 90% vs 70%) and the resulting crumb is dense and firm. The addition of calcium-stearyl lactylate at a level of 0.75% to a dough prepared from 70% wheat flour and 30% cassava flour resulted in an improvement in volume and crumb softness (420).

Several other studies are underway at Campinas, Rio de Janeiro, and Lima to improve flours in which cassava is incorporated by adding calcium-stearyl lactyl lactate as a conditioner. Workers at the Instituto de Tecnologa Agricola e Alimentar (ITAA) in Rio de Janeiro have succeeded in obtaining breads with satisfactory characteristics using 20% of nonwheat flours.

Tapioca Macaroni:

Bains et al. (79) reported a pilot plant study in India wherein four tapioca macaroni blends containing 18-20% protein had been prepared utilizing:

A. Tapioca flour, 50 parts; peanut flour, 25 parts; semolina, 22.5 parts; and casein, 2.5 parts.

B. Tapioca flour, 47.5 parts; peanut flour, 30 parts; and semolina, 22.5 parts.

C. Tapioca flour, 35 parts; peanut flour, 25 parts; semolina, 30 parts; and non-fat milk solids, 10 parts.

D. Tapioca flour, 35 parts; peanut flour, 25 parts; semolina, 25 parts; and chick-pea flour, 15 parts.

Each substrate was fortified with vitamins A, B_1, B_2, D, pantothenate, $CaCO_3$ and Ca_3PO_4. Sufficient boiling water was added to obtain a fairly stiff dough which was then extruded, passed through a pre-drier, steamed and dried at 55°C to a moisture content of 8-9%. The products were found palatable and cooked to a soft texture. About 1/3 of the vitamin A and less than 1/10 of thiamin and riboflavin were lost during processing. Blend A gave best growth of rats.

It was found that a considerable portion of milk in the diet could be replaced by enriched tapioca macaroni. The protein efficiency ratio (PER) of the processed products A, B, C, and D were 1.73, 1.47, 2.08, and 1.92, respectively, while the corresponding values for the unprocessed blends were 2.02, 1.74, 2.42, and 2.15. It was pointed out that adequate precautions needed to be taken to prevent the loss of nutrients during processing and that additional lysine and methionine would further improve nutritional qualities.

Fortified Cassava Flour:

High protein flour mix is being considered by the Brazilian National Institute for Social Security (INPS). Fortified cassava product consisting of the flour plus adequate amounts of a suitable source of protein such as fish protein concentrate (FPC), soy protein isolate (SPI),

food yeast or casein has been suggested for mass feeding since cassava is one of the products in the normal food patterns of tropical people. In addition, it would be desirable to insure the presence of amino acids and vitamins in such a fortified flour.

RECOMMENDATIONS

Cassava enjoys a poor competitive position when compared with the world's four major sources of starch -- corn, wheat, rice and potatoes. While the plant has sufficient desirable characteristics that it should make a much more significant contribution to the economy of the tropics than it does, the following changes must be made if this is to be accomplished:

1. Highly productive, disease resistant and non-toxic nutritious varieties must be selected.
2. Adequate pure soft water must be available.
3. Mechanization must be sufficient to permit efficient and sanitary processing.
4. Sufficient production of cassava must prevail to assure continuous and adequate supply to the processor.
5. Processing practices must be efficient and the quality of products derived from such processes must be uniform.
6. Functional and nutritional properties of cassava products must be improved.

The engineering technology needed for developing processing plants does not exist in many of the developing countries at present. The cassava processing industry is plagued with inadequate supply, poor utilization of by-products and lack of highly trained technicians. Land, labor and

production technology are generally available but very little has been accomplished in molding these into a cohesive unit with the main objective of providing a constant supply of raw material for processing.

The quality of cassava products can be markedly improved by selecting proper varieties. This needs to be determined not only in terms of yield per hectare but on the basis of protein and vitamin content and consideration must also be given to the functional characteristics of the starch and other components that are present.

The enhancement of the protein content of cassava, as with other root crops, has lagged far behind similar programs for cereal grains. Yet genetic improvement and fortification have made a start with the interesting research now underway at such institutions as the Centro Internacional de Agricultura Tropical (CIAT) in Palmira, Colombia, and the Instituto de Tecnologia Agricola e Alimentar (ITAA) in Rio de Janeiro. For example, at CIAT, the "Llanera" cultivar is known to contain 7% protein on a dry weight basis as compared to the typical 1-3% in most varieties. Some cultivars were reported by Jennings (400) to have protein values greatly exceeding 6%. At ITAA in Rio de Janeiro (518), experiments are underway with yellow fleshed varieties known to have higher carotene values. Further research in both of these areas should prove fruitful.

The starch produced from cassava is not accompanied by gluten as is the case in wheat flour. Consequently, the absence of this protein causes bread that is baked from cassava flour to be much heavier and more dense in appearance. Methods of mixing, together with certain additives such as calcium stearyl lactyl lactate as conditioners have

resulted in doughs that have improved volume and crumb color and texture. Cassava could be used in higher proportions in breads and other bakeries if methods of incorporation were altered, i.e., by mixing for longer periods of time, use of different temperature-time relationships in baking and changing the type of ingredients added. Binding agents such as glyceryl monostearate could be used to provide satisfactory dough and loaf structure. This type of work is most valuable and should be expanded.

Cassava starch or flour has little nutritive value other than that contributed by its carbohydrate content. Flours fortified with fish protein concentrate, with soy protein isolate, with torula yeast and with caseinate should be experimentally prepared. The one or two with the highest acceptability value, as determined by taste panels, should be made available for mass feeding to further delineate consumer acceptability. Similarly, a cassava macaroni enriched by using varying proportions of cowpeas, opaque-2 and floury-2 corn, ground nut meal, soybean meal, high protein rice and wheat varieties could be prepared. The ultimate products would add variety and serve as a better nutrient source.

The amino acid content of cassava flour can be markedly improved by the addition of soy flour, peanut meal or flour, or by incorporating appropriate amounts of deficient amino acids such as methionine, tryptophane and lysine directly. Also, the use of blends containing sizable amounts of cassava together with wheat or rice flour could yield bakery products of improved nutritional value. This work should be greatly expanded.

Usually the processing is primitive, poorly designed and implemented, and inefficient. Often the processor follows a procedure that he has learned from a predecessor or evolved by trial and error. Occasionally, innovative and ingenious techniques have been developed that permit extraction with excellent results. On the other hand, in a few instances certain steps in these processes are inadequate for obtaining a quality product while others are unnecessary. A review of the various procedures should be made and guidelines established to provide information concerning the contribution that each technique makes to the final product.

Additional industrial and food uses for cassava products are urgently needed. Hundreds of derivatives are in use including esterified starches such as starch phosphates and acetates, starch ethers such as the alkyl, carboxyalkyl and allyl starches, cationic starches, cross-linked starches, oxidized starches and starch graft copolymers. Recent research is presenting other possibilities using starch derivatives such as starch aldehyde reaction products, starch alkoxides and deoxystarches. In total, modified and derived starches represent tonnages of billions of pounds of raw starch. Corn starch, the cereal starches and potato starch have captured the greatest share of these markets. Cassava starch could just as easily serve as the basic material for most of these uses.

Research on methods of rapid detoxification of cassava tuber and the use of pure culture and controlled fermentation for the production of gari and/or similar products should be initiated. All processing and new product research should be coordinated with consumer acceptability.

Research programs need to be initiated in the major universities and experiment stations in many of the developing countries. Personnel in these institutions should include resident animal nutritionalists, food technologists and extension home economists who can determine satisfactory ways of producing, processing, storing and utilizing cassava so that a product of better and more uniform quality can be assured. In addition, such personnel should be charged with finding new and improved ways of utilizing the fresh root, chips, flour and starch and of getting this information to the people throughout the region.

CHAPTER IX

Economics of Cassava Production and Marketing[1]

ECONOMIC CONSIDERATIONS

The outstanding characteristic of cassava, from an economic standpoint, is its capacity to produce large amounts of food calories from indigenous resources. Conditions which are responsible for its prominence as a food crop in the tropics have also resulted in inadequate attention to the economics of the crop. Lack of attention to the economics of cassava probably results from its image as a "subsistence crop" and from the view that it reflects "a primitive agriculture." This lack of emphasis is revealed by the limited and inconsistent information in scientific literature on costs of producing cassava, supply-price relationships, and marketing systems. Similarly, there is little evidence of interest in the economic potentials of the crop by the research programs and agricultural development plans of tropical countries. Nevertheless, the crop remains an attractive source of low-cost calories and/or starch with sufficient potential to warrant more attention to the economics of its production and marketing.

Production Trends:

World production of cassava increased 59 percent from 1948-52 to 1966; an annual increase of about 3.3 percent. The increase in world production is attributable mainly to expanded acreage (164).

Among the major cassava producing regions of the world, Latin America achieved the largest gains in production during recent years.

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[1]Prepared by S. J. Brannen, Chairman, Department of Agricultural Economics, University of Georgia, Athens, Georgia.

Yields, which are highest in Latin America, are rising and the acreage devoted to cassava increased 34 percent during the 1961-67 period.

In 1967, cassava production in Latin America was greater than in Africa and approached 40 percent of the world total (233). Despite the increase in cassava output, per capita production has generally exhibited a negative trend, with notable exceptions such as in Brazil, Paraguay, Togo and Thailand (233).

Cassava yields and areas planted trends differ substantially among countries of each continent and between continents (146, 233). The tendency for yields to rise more slowly than output reveals the more general characteristic of the cassava production system, i.e., largely non-commercial and based mainly on use of land and labor resources.

Systems of Production:

Cassava production retains the vestiges of "traditional agriculture" which Schultz (664) defines as "farming based wholly upon the kinds of factors of production that have been used by farmers for generations." The typical farm is small, with the bulk of the labor force, management and even the capital provided by the same household (497). Output per farm is small, and largely for home use. Production in excess of family needs is sold or exchanged in local markets. Since producer inputs are largely land and labor and only a portion of the output is marketed, the systems of production under which cassava is produced throughout the tropics are poorly delineated and documented.

In many areas, cassava is not treated as an annual crop. In effect, storage in the field is achieved by harvesting the crop over a number of months. Different standards for measuring man-days of labor and other

factors provide data of questionable value for comparative analyses. Attention is being focused on these problems. Addition of economists to the staff at the International Tropical Agricultural Center (CIAT) in Colombia and the interest in adding economic research revealed at national, state and U. S. foundation centers in Brazil are noteworthy.

Even in countries where cassava production for commercial purposes is becoming more prominent as in Brazil (500), the production system is characterized by small units using largely manual methods

Jones (410) notes that the land exploitive nature of the production system can be easily overcome through direct action of farmers by returning plant nutrients to the soil, mixed cropping, and contour ridging. Unless opportunity costs for labor are positive (including the positive value, if any, of leisure) the incentive to reduce the labor requirements of the production system is low.

Resource Requirements:

Measured in terms of total resources, cassava production uses significant quantities of land and labor with small amounts of capital throughout the tropics. Yet, the 1967 crop of 9,378,000 hectares (233) based on the high estimates of 300 man-days per hectare required only small fractions of the total land and labor resources available for production of tropical food crops. For example, the land area equals only two percent of the 4.4 billion hectares capable of sustaining food crops.

Labor and/or capital requirements per hectare varies substantially. Even measures of resource requirements per ton show great variations (146). Generally though, the resource mix for cassava production is

heavily weighted toward labor and land supported by minimal capital. Use of some chemicals and machinery as substitutes for land and labor is beginning to emerge particularly in plantation production systems. As land and labor become less abundant in economic terms and the supply of capital increases, the latter resource will become more prominent in the mix of production inputs.

Relative Costs and Returns:

Costs for producing cassava are a function of input prices and quantities used. Similarly, yields and prices of cassava determine producers' gross returns. Butler (146) in his study found insufficient bases to draw definitive conclusions about total costs and profitability of cassava production. In terms of caloric output per hectare and per unit of labor, however, he demonstrated the superiority of cassava over maize, potatoes, and yams (146). However, Vries et al. (807) suggest that root crops tend toward equal production levels when length of growing season is properly considered. The difficulty in comparing production requirements, output and other data from different regions has been noted by Johnston (405, 406) and Jones (412).

Under tranditional farming systems, labor requirements are perhaps the best indicator of the cost of cassava production. Wide variations in reported labor requirements are due in part to variation in production methods and differences in measurement of the labor input. For example, Wrigley (841) reported labor requirement in the Belgian Congo of 315-316 man-hours for stick preparation, planting, weeding and harvesting an acre of cassava. In Uganda, the same operations take 756-896 man-hours for a comparable yield of four tons (429).

Johnston (405, 406) reports 111 man-days per hectare (362 man-hours per acre) for equivalent yields in the Belgian Congo Forest Zone. In the Philippines, cassava production required 1,867 man-hours and 185 hours of animal power per hectare (508) for a yield of 25 tons. Since weeding and harvesting of the crop required the largest amounts of labor, evaluation of different methods of harvesting found use of animals along with human labor to be the most economical (508).

In Latin America, Krochmal (429) found labor input requirements to range generally from 370 to 395 man-hours per hectare with a maximum of 494 hours for ten tons. Weeding required the most labor, but a single herbicide application reduced the labor for weeding from 178 to 5 hours per hectare. Somewhat lower man-hours per hectare have been reported in Brazil (806) and in Colombia (232). However, data from the Department of Agriculture, Sao Paulo, Brazil, reported by Critides (208) show that labor costs, even under partial mechanization and an average rate of $1.22 per day, amounted to more than 50 percent of the cost of production. This divergence of labor requirements drawn from the literature reveals the critical deficiency in the consideration generally given to the economics of cassava production.

Perhaps the most reliable evaluation of cassava costs and returns is that made by Suarez and Davis (731), which showed cassava could compete favorably in terms of net income per hectare with cotton, corn and sesame in the Atlantic Coast of Colombia. Critides' (208) report showed cassava to be profitable in Southern Brazil but he asserts that the "manioc industry in Brazil is a marginal one fraught with

uncertainties." He further concludes that a $4 per ton difference in farm price of cassava roots represents sufficient difference in cost per ton of cassava chips to make a region non-competitive in export markets (208). Cassava production costs reported by Critides (208) from undocumented sources for various countries ranged from $2.32 per ton for plantations in Nigeria to $14.24 per ton in El Salvador. Unfortunately, the costs are not comparable because of differences in items included and accounting methods used among countries.

Though inconclusive, available data indicate that the usual cost of producing cassava centers around $6.00 per ton. Even at 25 tons per hectare (which is far above the average yield but significantly below the potential), it is clear that returns to either land or labor would be low unless the price of cassava roots is significantly above the $3.74 to $10.00 per ton Critides cites (208).

One way of examining relative costs of cassava used by Jones (409) is to compare market prices of starchy staples. He found that where cassava is available in significant quantities, its products usually cost substantially less in caloric terms than its competitors. However, this does not reveal the rate of return to the resources employed in cassava production.

Studies in Colombia have shown profits from production of cassava varying from $3 to $33 per ton (232). Critides (208) cites a Honduras report where a price of $6.60 per ton yields a producer profit of $1.54 per ton. Also, he notes that "it is easier for farmers and plantation owners to turn a profit with other agricultural products" (208). Total gross sales per cassava producer in the northeast of Brazil averaged only about $100 in 1966 (500).

Given the yield levels that are typically achieved (Table 9-1), cassava production could hardly be generally profitable, except in terms of yielding labor income to producers, who may not have other superior alternatives. At $10, or even $20, per ton for cassava roots, 15 tons per hectare promises a gross return of only $150 to $300 per hectare. If nonlabor costs amount to as little as $6 per ton, the labor returns of $54 to $202 per hectare still yield low wage rates and incomes under typical systems of production and scale of operations.

The potential for substantial improvements in yields coupled with substantial reductions in labor requirements for weeding and harvesting offer great promise for improving costs and returns in producing cassava.

MARKETING

The commercial marketing systems depend on the cassava product forms and the stage of development of the market economy. These range from raw roots sold or bartered for direct consumption to processed products such as farina on to bread or frozen cassava. At first glance the local market system might appear to be simple, particularly where the raw product is sold directly to consumers through a local market.

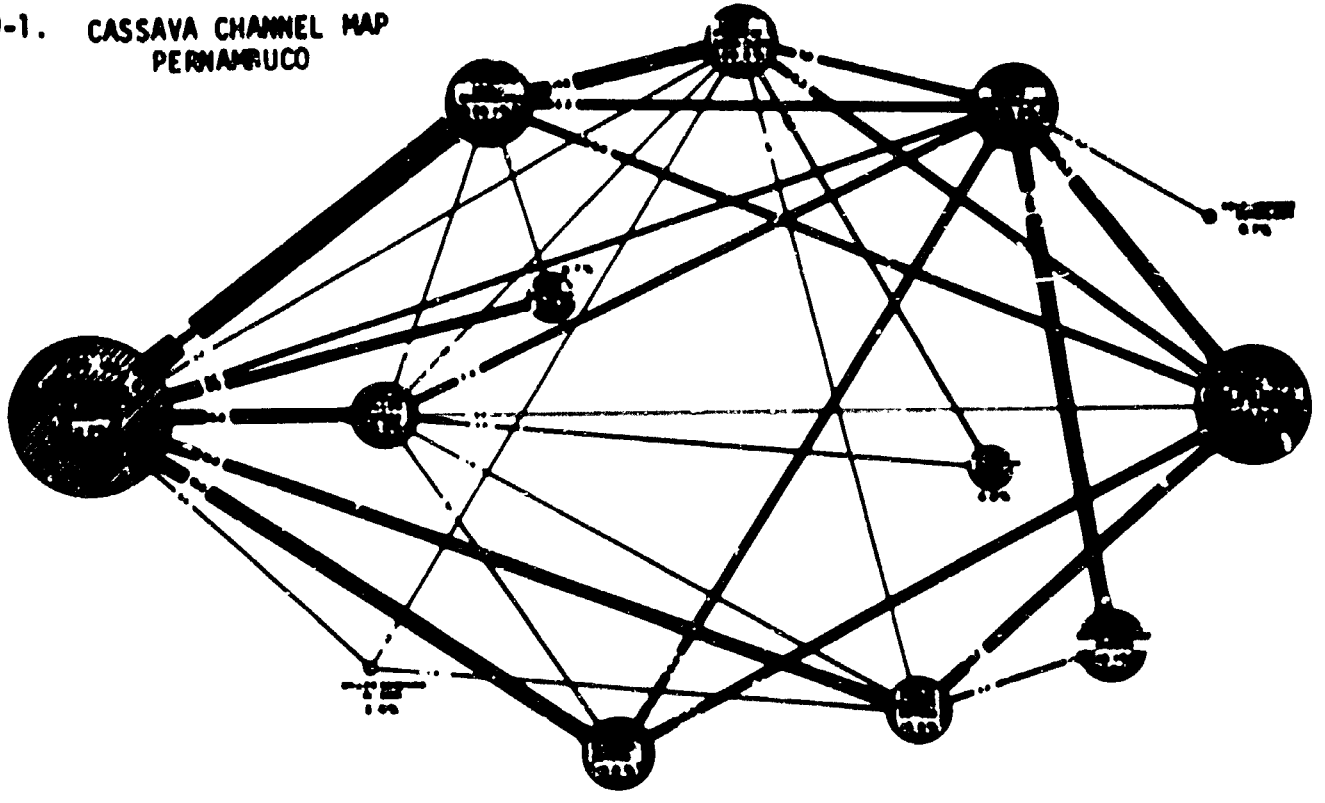
Where the local market system has been analyzed, the real world market system complexities begin to emerge. The best documented example of a cassava local market system is that of Northeast Brazil (500). Though characterized as "one step removed from subsistence farming and barter exchange," the market channel map for Pernambuco (Figure 9-1) shows the "diversity and complexity of a good approximation of the actual system" (500).

TABLE 9-1. Yields of cassava for Selected Countries in Africa, Asia, and Latin America, 1948-52 (average), 1952-56 (average), and 1962-66 (annual).

Country	48-52	52-56	1962	1963	1964	1965	1966
	Metric tons/hectare						
Congo (Kinshasa)	10.08	11.76	9.88	10.98	11.27	11.56	10.86
Ghana	7.68	8.71	13.46	7.48	7.56	7.77	7.77
Nigeria	5.77	5.98	6.18	6.18	6.09	6.09	5.77
Togo	5.08	5.89	7.28	7.88	6.38	7.37	7.08
Africa	6.36	6.88	6.47	6.58	6.67	6.59	6.47
Ceylon	3.20	3.00	6.29	7.57	8.18	6.18	5.98
India	5.38	6.92	7.08	7.08	11.55	11.56	12.86
Philippines	5.89	5.00	5.69	6.38	6.88	6.88	6.47
Taiwan	10.57	12.48	12.26	12.48	13.96	14.36	15.16
Thailand	18.75	14.05	17.05	15.16	14.76	12.52	14.96
Asia	6.99	5.73	8.18	7.88	8.47	7.32	8.09
Brazil	12.77	12.86	13.37	13.75	14.16	14.27	13.87
Colombia	10.28	11.18	7.28	7.19	6.59	7.77	6.88
Venezuela	3.49	4.19	12.48	13.66	12.57	12.28	12.48
Latin America	11.38	11.47	12.16	12.36	12.48	12.77	12.48

Source: FAO Production Yearbook, 1967 (292)

FIG. 9-1. CASSAVA CHANNEL MAP
PERNAMBUCO



Source: Michigan State University (500)

Cassava enters this system as farina (rather than as raw material) crudely milled with manual equipment by the farmers. Quality requirements are ineffectively transmitted to farmers; delayed harvest is the only method of supply control or storage; and merchant credit is used heavily by producers.

At best, the local market system for cassava might be characterized as a developing system where uncertainty and risks result in substantial instability of both market structure and performance.

The total market demand for cassava in producing regions is a function of domestic consumption and export trade. Butler's study (146) provides an overview of cassava marketing and is the basis for most of the following sections.

Domestic Consumption:

The amount of cassava presently being consumed domestically varies considerably between areas, countries, and regions within the same country. For example, Table 9-2 indicates that the use of cassava is much greater in the southern region of Nigeria (higher rainfall) than it is in the northern region (less rainfall). The cereals apparently become more important in diets as the climate becomes drier.

Cassava is consumed in several different forms and these forms and amounts vary from area to area in the same region or country. Table 9-3 shows consumption of cassava in different forms. It suggests that when consumption of one form declined another increased. Poleman (609) found this to be true in a recent study conducted in Ghana. There he found an apparent aversion to dried cassava, but did not find evidence of a similar lack of preference for fresh cassava roots. In fact, the data

TABLE 9-3. Daily Purchases Expressed in Calories, and Price per 1000 Calories of Selected Staple Feeds, Kumasi and Sekondi-Takoradi, Ghana, 1955.

	Kumasi		Sekondi-Takoradi	
	Purchases (cal. per person/day)	Price (cents per 1000 cal.)	Purchases (cal. per person/day)	Price (cents per 1000 cal.)
Cassava and products				
Fresh roots	243	2.68	456	2.73
Gari (meal)	46	2.94	64	3.23
Kekonte (dried roots)	212	1.63	57	2.69
Plantains	389	3.06	168	4.32
Yams	123	5.91	49	7.64
Maize and products				
Kenkey	50	5.74	188	5.33
Dough	43	--	49	--
Rice	101	5.20	111	5.28
Cocoyams	98	3.76	15	5.02
Bread	27	11.03	47	11.70
All starchy staples	1,364	--	1,260	--

Source: B. J. Johnston and H. Kaneda (406)

suggest a tendency for fresh roots to be substituted for the dry products as income rises (609).

A study in Trinidad showed a relative increase in per capita consumption over a ten-year period (Table 9-4). Alexander (26) found that with increased incomes the amount of starchy staples, including cassava, declined as a part of consumption (Table 9-5).

The Economic Research Service of the U. S. Department of Agriculture found that consumption per capita had declined in Colombia, South America. The report states that as farmers migrated to urban areas where they had to purchase all their foods, they switched from cassava and plantains to rice and wheat (263).

In Thailand, where production of cassava has increased sharply since 1956, only a minor share of output is consumed domestically. Cassava occupies about two percent of the country's planted area and it is almost entirely for export (262).

Statistics on direct consumption are not readily available or reliable. Expansion of world production by 28,828,000 metric tons between 1961 and 1967 indicates the potential increase in cassava consumption. Assuming that consumption was equal to production, domestic consumption increased proportionately.

Past experience in European countries and the United States shows that with economic growth and increased incomes there are changes in food consumption patterns. These changes involve a decreasing proportion of income being spent for food, and a switch from the less expensive starchy staples to the more expensive meats, vegetables, and fruit. Johnston (389) points out that in the United States per capita

TABLE 9-4. Per Capita Consumption in Kilos of Yams, Sweet Potatoes, Cassava, and Irish Potatoes, Trinidad, 1954-63.

Year	Yams	Sweet Potatoes	Cassava	Irish Potatoes
1954	5.3	7.0	3.4	13.0
1955	5.0	7.8	3.5	15.1
1956	5.8	9.0	5.1	13.7
1957	4.3	7.0	31.	13.6
1958	4.4	6.7	3.1	13.6
1959	4.2	6.8	3.1	13.0
1960	4.3	6.5	3.1	13.0
1961	3.9	3.9	3.7	12.2
1962	2.4	3.0	3.4	13.5
1963	2.7	3.1	4.0	12.5

Source: M. N. Alexander (26)

TABLE 9-5. Weekly Purchases Per Household of Starchy Roots and Tubers by Income Groups, One Week, 116 Households, Trinidad, March 1967.

Commodity	Average Annual Family Income $2,500	$8,500	$17,500
	----------Kilos----------		
Yams	0.81	0.63	0.42
Sweet potatoes	1.02	0.60	0.45
Cassava	0.61	0.30	0.26
Irish potatoes	1.58	1.74	1.68

Source: M. M. Alexander (26)

utilization of white potatoes from 1909 to 1954 showed a decline from 84 kilos to approximately 45 kilos per year and sweet potatoes from 12 kilos to about 3.2 kilos per year (406). During the same period, per capita consumption of wheat flour declined from 98 kilos to 57 kilos and consumption of corn meal and flour fell off most sharply of all -- from 24 to 5 kilos (406). In some countries the consumption of root crops has increased while use of grain crops has decreased. This trend is true, for example, in parts of India and Java where cassava is substituted for rice (406).

It is difficult to project a consumption trend with any certainty because of the many factors and uncertainties of the future. It is possible, however, to cite some of the more important factors which will determine to some degree the use of cassava in the future. The most influential factors are likely to be: (1) changes in relative prices of cassava and competing and substituting commodities; (2) government attitude toward cassava with respect to encouraging its cultivation by subsidizing investment, development schemes, and in some cases, required use of certain amounts of cassava flour for domestic consumption; (3) increases in per capita incomes; (4) changes in taste and preferences; and (5) increased use as an animal feed (406).

World Trade:

Major Exporting Countires.--Cassava is grown in most tropical areas but the major sources of the cassava which enters international trade are Thailand, Brazil, Indonesia, Madagascar, Togo, and Malaysia. Cassava is exported either as dried cassava roots or, after processing, as cassava starch or "grocery" cassava (809).

Brazil is by far the world's largest producer of cassava. Brazil produced 24,710,000 metric tons of cassava in 1966. This amount was greater than the entire Asian production by 6,464,000 metric tons. However, most of the annual crop is used for domestic consumption (809). According to the United States Department of Agriculture, only one percent of the total Brazilian output is exported (263).

Indonesia was the world's principal exporter of cassava products before World War II (809). As a result of the damage incurred by the starch processing plants during the war, production of starch is now very small. Subsequently, Thailand became the world's principal exporter of cassava products, even with production much lower than Brazil. In Thailand, cassava is not important in the domestic diet. In 1967, Thailand exported 890,506 metric tons of cassava products worth $35,951,807 (Table 9-6).

Togo has increased annual production in recent years and now produces about one million metric tons each year. Exports from Togo are, however, very small and mainly exported to France. In Togo, cassava is a main staple in the diet. Exports of cassava products from Madagascar, India, and Taiwan account for only a small proportion of the annual cassava crop (809). Other main sources of cassava for export are Mainland China, Angola, Tanzania, and Malawi (384).

Major Importing Countries.--The United States and European countries are the main importers of cassava products. The United States was the primary user of cassava products until 1962, at which time the EEC countries started to import large quantities of cassava products. Imports into the United States fluctuated a great deal

TABLE 9-6. Volume, Value, and Price of Cassava Exports from Thailand, 1960-67.

Year	Metric tons	Value	Dollars/ton
1960	309,395	$13.975,094	$45.17
1961	488,584	21,493,976	43.99
1962	442,668	20,385,542	46.16
1963	471,042	21,156,627	44.92
1964	814,222	31,469,880	38.65
1965	792,825	32,578,313	41.09
1966	784,998	33,060,241	42.12
1967	890,506	35,952,807	40.37

Source: The Thai Tapioca Trade Association (756)

during the period 1951 to 1968 (Table 9-7). This was probably due to the variability of supply. The trend in imports shows an increase over this 18-year period, by 7,828 metric tons each year.

The EEC is the other major importer of cassava products. Imports do not show the large fluctuations experienced for the United States. This finding may be misleading, however, because the data are for a five-year period and may not be a long enough period to show large changes. However, total imports showed a substantial increase during this period from 413,705 metric tons in 1962 to 883,514 metric tons in 1966 (Table 9-8). West Germany, the Netherlands, and Belgium increased imports. France showed a decline of imports for the same period.

Uses in Importing Countries.--The United States is the largest single market for cassava starch importing most of it from Thailand (809). Cassava starch accounts for less than one percent of the total consumption of starch in the United Kingdom (809). France and the Netherlands import small quantities of cassava starch, but with potato and maize starch becoming more popular, French and Dutch imports are rapidly diminishing (384). Japan is potentially a large market for cassava starch and Thailand, due to her nearness to Japan, could possibly be a prime exporter to Japan in the future (384).

Imports of cassava starch into the United States were at one time mainly used in food products. In recent years, however, cassava flour has been used in industry for "sizing" paper (756). Cassava starch is widely used in the paper and paper box industry which consumes approximately 70 percent of the starch imported into the United States (809). Cassava starch, potato starch, and corn starch may be interchanged for

TABLE 9-7. United States Imports of Tapioca and Cassava, 1951-68.

Year	Quantity (metric tons)	Value (dollars)	Price/ton (dollars)
1951	54,990	5,644,500	102.65
1952	30,380	3,813,267	125.52
1953	33,600	5,670,012	168.75
1954	31,651	4,105,380	129.71
1955	65,172	6,268,954	96.19
1956	76,007	7,080,189	93.15
1957	81,731	7,889,019	96.52
1958	89,327	7,794,491	89.27
1959	113,072	8,407,319	74.35
1960	139,990	9,976,361	71.27
1961	153,319	10,790,973	70.38
1962	81,624	6,040,000	73.90
1963	122,219	9,124,737	74.66
1964	147,209	9,565,692	64.98
1965	179,013	12,195,021	68.12
1966	170,347	11,461,321	67.28
1967	152,039	10,686,369	70.29
1968	96,899	7,058,351	72.84

Source: United States Department of Commerce (775)

TABLE 9-8. Imports of Cassava Products into the European Economic Community, 1962-66.

Country	1962	1963	1964	1965	1966
	'000 metric tons				
Germany					
dried roots	66,043.5	147,690.5	272,585.5	387,962.3	433,320.0
meal	300,063.1	239,576.4	188,947.8	131,671.3	248,389.3
total	366,106.6	387,266.9	461,533.2	519,633.6	701,709.3
Netherlands					
dried roots	25.0	567.0	9,788.0	72,093.0	90,626.0
meal	1,186.0	4,171.0	7,247.0	4,395.0	4,904.0
total	1,211.0	4,738.0	17,035.0	76,488.0	95,530.0
Belgium					
dried roots	5,741.2	47,342.3	80,782.0	95,925.3	63,524.1
meal	17,216.8	24,724.9	24,609.0	4,277.4	7,100.5
total	22,958.0	72,067.2	105,319.0	100,202.7	70,624.6
France					
dried roots	23,429.0	19,555.0	18,013.0	17,400.0	15,650.0
meal	---	---	---	---	---
total	23,429.0	19,555.0	18,013.0	17,400.0	15,650.0
Italy					
dried roots	---	---	---	---	---
meal	39.9	---	---	292.0	---
total	39.0	---	---	292.0	---
Five countries					
dried roots	95,238.7	215,154.8	381,168.5	568,380.6	623,120.1
meal	318,465.9	268,472.3	220,803.8	140,635.7	260,393.8
total	413,704.6	483,626.1	601,971.3	709,016.3	883,513.9

Source: International Trade Centre (384)

a large number of uses. The extent to which cassava starch is used depends upon its price in relationship to that of the other starches. With competition from these other starches, cassava starch must be of high quality and competitively priced (809).

The primary use of cassava in the European Economic Community (EEC) is in the form of chips. The chips are used almost entirely for animal feed (809). The European market for cassava starch and grocery products for food use is relatively small (809). The dried cassava roots and meal are used for animal feeds while the starch is used for industrial purposes.

Different feed grains can be interchanged for livestock feeding and a balanced starch diet can be composed of a wide variety of feed grains. The major factors determining the feed composition are the patterns of local grain production and relative prices of imported grains (or cassava) (384).

Import Price Trends.--Prices for imports into the United States declined from a high of $168.75 per ton in 1953 to a low of $64.98 per ton in 1964. This was a decrease of $103.77 per ton over an eleven-year period. Prices were relatively high during the early 1950's, but beginning with 1955, showed a general decline (see Table 9-7). Prices have remained near $70.00 per ton from 1959 to 1968. Unlike the United States, in the EEC, prices have remained relatively stable (Table 9-9).

Export Prices.--Wholesale export prices for cassava show a slight downward trend. The prices for cassava exports from Togo to France show an average decline of 0.5939 of a cent per kilogram for a 14-year period (Table 9-10).

TABLE 9-9. Import Prices of Cassava in Dollars/Ton in the European Economic Community, 1962-66.

Country	1962	1963	1964	1965	1966
Germany	65.97	59.98	58.19	64.80	65.32
Netherlands	55.24	53.28	56.06	62.97	60.80
Belgium	66.06	61.30	59.72	65.01	65.77
France	73.83	69.38	70.17	70.66	76.76
Average	66.39	60.50	58.76	65.23	65.07

Source: International Trade Centre (384)

TABLE 9-10. Import Prices in U. S. Cents/kg of Tapioca to France and Wholesale Prices in Malaysia, 1952-65.

Year	France I[a]	France II[a]	Malaysia
1952	33.3	23.7	18.2
1953	26.8	14.5	15.3
1954	26.7	22.4	10.0
1955	27.7	24.6	11.0
1956	28.9	25.0	10.3
1957	26.0	23.0	9.0
1958	23.9	18.6	10.1
1959	20.7	17.7	10.0
1960	20.7	17.8	8.2
1961	20.0	17.0	8.9
1962	18.3	16.8	11.5
1963	18.8	16.9	9.3
1964	19.7	16.8	7.2
1965	19.7	17.0	8.5

[a]I is Togo No. 2; II is Madagascar extra white.

Source: FAO Production Yearbook, 1966 (291)

Wholesale prices in Malaysia also show a general tendency for decline but not as fast as prices for cassava from Togo. In Malaysia, the average price decline was about 0.50 of a cent per kilogram. The large differences between Togo prices and Malaysia prices were caused primarily because Togo exports were manufactured cassava, while the Malaysia product was raw cassava.

Thailand had large increases in exports with an accompanying decline in the price per ton (Table 9-11). Prices showed an average decline of 0.767 cents per ton over an eight-year period. Quantity exported increased by about 581 thousand metric tons from 1960 to 1967 while prices per ton decreased from $45.14 to $40.37. The increase in quantity was sufficient to cause an increase in value of cassava exports from about 14 million dollars to 36 million dollars per year indicative of an elastic demand

World trade prices have generally exhibited a decline except in the large market for cassava of the EEC. Price declines in the United States may have been due to increased competition from other starches and increased availability of supplies. The declines in export prices may have been caused by increasing competition from other countries exporting cassava.

Problems of Cassava Trade:

The cassava trade has many problems but only the most important will be discussed here. In general, the main difficulties encountered with cassava trade are (1) quality, (2) transportation, and (3) prices of cassava relative to prices of its substitutes.

Quality.--The standards for quality cassava differ among the importing countries. West German manufacturers are less strict than

TABLE 9-11. Volume, Value, and Price of Cassava Exports from Thailand, 1960-67.

Year	Metric Tons	Value	Dollars/ton
1960	309,395	$13,975,904	$45.17
1961	489,584	21,493,976	43.99
1962	442,668	20,385,542	46.16
1963	471,042	21,156,627	44.92
1964	814,222	31,469,880	38.65
1965	792,825	32,578,313	41.09
1966	784,998	33,060,241	42.12
1967	890,506	35,952,807	40.37

Source: The Thai Tapioca Trade Association (756)

the Dutch and Belgians, who are much more quality minded. Large manufacturers and cooperatives in all three countries definitely prefer higher quality cassava (384). Angolan cassava is considered superior, while Congo (Kinshasa), Tanzania, Malawi, Brazil, Indonesia, and Mainland China are also considered to export excellent quality products (384). African cassava chips are generally better in quality and would be used more if regular supplies were guaranteed (384). The standards are usually based on starch content (minimum), moisture content (maximum), raw fiber content (maximum), ash (or sand) content (maximum) (384). The standards for Thailand cassava chips set by Dutch cooperatives, and also accepted by the Dutch independent manufacturers are contained in Table 9-12.

Shipments may be rejected if starch content is less than 68 percent, raw fiber content exceeds seven percent, or ash content exceeds 5 percent. The buyer may refuse delivery even when only one of the specifications is not met (384).

Another problem which must be considered is that cassava must never be exposed to water or moisture during or after processing. This removes the starch, the color turns brown, black, grey, or green and the feeding value deteriorates. Moisture also encourages bacterial growth. A high bacteria content is particularly dangerous for young pigs and poultry. Swine become sick with diarrhea and pigs sometimes die after being fed moldy cassava flour (384). In this respect, it is vitally important that exporting countries intensify quality control, thus producing a product which can compete with maize and barley.

Transportation.--Freight rates are very important in the cassava trade, since they represent a substantial part of the c.i.f. price.

TABLE 9-12. Standards for Cassava Chips from Thailand as set by Dutch Cooperatives, 1967.

Ingredient	Percent
Starch	70 (minimum)
Raw fiber	5 (maximum)
Ash	3 (maximum)
Moisture	14 (maximum)

Source: International Trade Centre (384)

The conference rates for Thailand and Indonesian cassava to Europe in late 1967 are shown in Table 9-13. At the same time, freight rates from Tanzania for cassava roots in bags were $12.60 per metric ton (384). Besides using regular conference line ships, some shippers also charter vessels in an attempt to reduce transport costs. These ships were often old and transport conditions were poor (384). It has been estimated that at times, 60 percent of such shipments arrive in a poor state, because they had been exposed to molding, heating, and sweating, particularly on a long voyage (756). African suppliers would benefit in this respect from the advantages of shorter distances and reduced length of trips to the European markets as compared with Asian voyages.

Competitive Products.--The two principal raw materials competing with cassava as a livestock feed are barley and maize. Maize is superior in feeding value since it contains more protein and fat. Oats, rye, beet pulp, and sweet potatoes also compete with cassava as a livestock feed, but to a lesser extent. Their competition is not substantial at present but could affect cassava sales if they are imported in larger quantities. Since the introduction of the Common Agricultural Policy which has raised prices of feed grains, the compound feedingstuff industries of West Germany, the Netherlands, and Belgium have been trying to reduce costs and are looking for substitute raw materials. Thus, almost all manufacturers now use cassava (384).

POTENTIALS FOR ECONOMIC DEVELOPMENT

Cassava represents an unexplored frontier for economic development of tropical countries. The crop represents a relatively low cost source of food energy and its various food forms are established in the

TABLE 9-13. Freight Rates for Different Forms of Cassava from Thailand and Indonesia to Europe, Late 1967[a].

Country and Form	Cost
Thailand	
Cassava chips in bulk	$24.85 per long ton
Cassava chips in bags	23.59 per long ton
Cassava pellets in bulk	14.42 per long ton
Cassava pellets in bags	15.68 per long ton
Cassava meal in bags	16.94 per long ton
Indonesia	
Cassava roots in bags	$19.75 per long ton
Cassava chips in bags	16.80 per long ton
Cassava meal in bags	13.65 per long ton

[a]Prices quoted are converted from the pound sterling before devaluation on 18 November 1967.

Source: International Trade Centre (384)

consumption habits of the rapidly growing populations of developing countries where it is produced. Its nutritional deficiencies can be remedied (409) as is now being tested by the Institute of Agricultural Technology (Brazil) in terms of protein fortification. The annual rate of growth in output of about 3 percent per year attests to the population elasticity of demand for cassava products. As a relatively lower priced food commodity, the substitution effect (positive price elasticity) tends to offset the income effect (negative income elasticity) on demand. Hence, even under conditions of growth and rising per capita incomes, increases in demand should accompany population growth. Further research is needed to specify and measure the parameters of demand functions for different regions and establish the region and world market constraints on the potential economic (rather than physical) supply of cassava products. For example, studies in Ghana revealed that consumption habits did not change much as people migrated to cities and that there is a tendency to substitute fresh roots for dry products in consumption as incomes rise (609).

Export Demand:

Consumption of cassava in the United States has steadily increased from 1951 to 1968. If cassava supplies are available, of good quality, and priced to compete with other starches, cassava might continue to hold its place in the United States market. Cassava is also increasing in importance as a food product in cities with large concentrations of Cuban and Puerto Rican populations. Cassava is being grown in the Miami, Florida, U.S.A., area for sale in the City of Miami. It is also being flown to New York State to satisfy the needs in New York City, U.S.A. Increasing numbers of people accustomed to having cassava are

coming to the United States, resulting in an increased demand. Latin American countries are already supplying these markets and would continue to have the advantage over African and Asian producers.

The EEC has shown large increases in the use of cassava as a livestock feed. West Germany, in particular, has increased her imports substantially Cassava must be able to compete with barley and corn. If cassava can continue to arrive in Europe at a competitive price, it will be used (384). It is pointed out that manufacturers take two important factors into consideration -- feeding values and prices. It is important that the imported cassava not only be priced competitively, but it must also be of high quality. Since consumption of cassava products by the compound feedingstuff industry is expected to increase in the future, it is vitally important that producing countries intensify quality control tests (384). Africa will have the advantage of being closer to the EEC thus shipping costs will be less. This should enable Africa to supply cassava at a more competitive price than producers in Asia. In the Asian area, Japan is an expanding import market and Asian producers would have an advantage because of their relative closeness to Japan. Above all a dependable supply is essential for the development and maintenance of markets.

The potential for expanding output of cassava is constrained only by total demand and prices relative to production costs. Scarcity or prices of production inputs, particularly for land and labor, offer no real limitation on production expansion. The possibilities for doubling, or even tripling, total output from existing hectarage and manpower with nominal increases in capital inputs are not unrealistic.

Personal contacts with scientists in Latin America revealed market constraints as the major factor limiting expansion of output under traditional systems of production, and that economic factors such as relative prices of chemicals, macninery, and other capital items rather than technology were deterring changes in resource mix and output levels in cassava production as well as processing.

Investment Requirements:

The image of the crop alluded to earlier probably accounts for the unfavorable "developmental climate" for cassava. One Brazilian scientist revealed that no one was interested in investing in cassava production or processing because credit policies (national policy) favored other types of agricultural investments. This policy environment fails to recognize the contribution of an exportable surplus to trade balances or the comparative economic advantage of substituting domestic cassava for imported food and feed products.

The important point is that favorable national policies for cassava development are essential to foster not only the relevant economic research but also to provide the public investment and generate the private investment that is needed.

Organization of the cassava industry around the abundant natural and human resources provides "a priori" a basis for high marginal productivity of capital investments in the industry. Unfortunately, the existing scientific literature does not provide the data or analyses to indicate the levels and kinds of investment and alternative pay-offs from them. Future research must explore the effects of such investments with appropriate emphasis upon priorities for investments at different

structural levels in the industry. Until the comparability of data is improved and further economic research is established, the potential effects of cassava's potential on food supply, incomes and employment can only be generalized ... in terms of direction of the effect ... which certainly appears to be positive

Available evidence indicates that initial research and development emphasis should be focused in South America where positive public and private interests may be more readily achieved. The existing industry seems to be positively oriented toward improving yields and product quality and a base of scientific capability has been established to which economics research could be added.

CHAPTER X

Summary and Recommended Research Programs[1]

Cassava, the world's 7th ranking staple crop, represents an inadequately explored commodity for economic development. It is a relatively low cost source of food energy and its various food forms are well established in the consumption habits of the people. Since it is so well accepted by the general public, there are indications that even under conditions of growth and rising per-capita incomes, increases in demand will accompany population growth. Although it has nutritional deficiencies in terms of human and livestock consumption, these can be remedied through breeding and/or fortification of the processed products with protein, amino acids and vitamins.

The European Economic Community (EEC) has shown large increases in the use of cassava as a livestock feed. West Germany, in particular, has substantially increased imports, and if cassava chips can be placed in Europe at competitive prices with barley and corn it should be able to capture a larger part of this market. However, feed manufacturers in Europe take such important factors as feeding value, price, and a dependable supply into consideration. Therefore, imported cassava not only must be priced competitively, but it must be high quality. Since consumption of cassava products by the EEC is expected to increase in the future, it is vitally important that any manufacturer of chips pay particular attention to quality control if they expect to export to this market.

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[1]Prepared by C. H. Hendershott, Chairman, Department of Horticulture, University of Georgia, Athens, Georgia.

The potential for expanding output of cassava is restricted only by total demand and prices relative to production costs. At the present time, the scarcity or prices of such production inputs as land and labor appear to offer no real limitation on production expansion. The possibilities for doubling, or even tripling, total output from existing acreage and manpower with nominal increases in capital inputs are not unrealistic at the present time. Generally, limited agronomic technology and market instability are the major factors restricting cassava expansion at this time. Other factors such as relatively high prices of chemicals, machinery, and other capital items and poor processing technology are further impeding output levels.

Cassava's image as a subsistence crop and not as a potentially great agricultural asset probably accounts for its unfavorable developmental climate. Some people are of the opinion that interest in investing in cassava production or processing is low because national credit policies favor other types of agricultural investments. This policy environment apparently fails to recognize the contribution of an exportable surplus to trade balances or the comparative economic advantage of substituting domestic cassava for imported food and feed products. Therefore, favorable national policies are essential to foster research and generate the public and private investment needed for cassava development. Unfortunately, this team did not have the time and, furthermore, the scientific literature available does not provide the data or analyses to indicate the levels and kinds of investment available in all countries of the world and alternative pay-offs from them.

Until the comparability of data is improved and further economic research is established, the ultimate effects of cassava's potential on food supply, incomes and employment can only be generalized ... in terms of direction of the effect ... which certainly appears to be positive at the present time.

Cassava is apparently relatively free from insect and disease attacks. However, the literature, on a world-wide basis, reveals that certain insects and diseases are sometimes a problem and should not be overlooked in a program on yield improvement.

Viruses can be and are a serious problem in some areas of the world. Therefore, it is probable that they are present in many of the varieties used in the various cassava producing countries. However, it is not known how many different viruses are involved. It is quite possible that symptoms of certain viruses are masked under the various environmental conditions. Thus, their influence on yield reduction would go unobserved and also be difficult to ascertain.

Another aspect of insect and disease infestations which should not be overlooked in the production program is that under certain crop rotation series a definite increase in root rot caused by Phytophora can occur. There is evidence that this has occurred on cassava in rotation with rice and peanuts in Central Africa which resulted in a severe decrease in yield of all crops in the rotation series.

Post-harvest losses due to microorganisms and physiological degradation presently appear to somewhat limit the commercial storage, marketing and exporting of cassava, and should not be overlooked in the research program.

The prospect of improving the yield, nutritional value, and disease and insect resistance of cassava appears to be good. The literature shows that cultivars and species with high crude protein content and disease resistance are available. There appears to be no serious problem in obtaining a gene flow from one species or cultivar to another. The morphological classification of cassava cultivars developed by Rogers and Fleming, the systematic computer evaluation of the genetic variability existing in the genus Manihot being conducted by Rogers and associates and the work being conducted at CIAT (Colombia) and IITA (Nigeria), should be an invaluable aid to plant breeders in designing and conducting a strong breeding and selection program when initiated.

Cassava utilization in livestock feeding and production has a great potential. The leaves, roots and by-products of manufacturing can be utilized in feeds for hogs, cattle, chickens, and other livestock. Although most varieties are not at present equal to cereal grains in nutrient content, many have the unique characteristic of high yields and good growth potentials on poor soils and under adverse climatic conditions where cereal grains cannot grow or produce adequately. Recently, a specific cultivar named "Llanera" was reported in Colombia (CIAT) to yield an average of 40 T/ha under farm conditions with a potential of 100 T/ha on deep and fertile soils. The analysis of this variety shows a content of 7.2% crude protein, on a dry weight basis, with a quality, expressed by amino acid profile, similar to the protein of common corn, but inferior to opaque-2 high lysine corn (486). Probably one of the greatest uses of cassava in the future will be in utilizing it in animal feeds and thus making a significant contribution to the energy and protein needs of the human race.

The enhancement of the protein content and quality of cassava, as with other root crops, has lagged far behind similar programs for cereal grains. Yet genetic improvement and fortification have made a start with the interesting research now underway at such institutions as the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia, and the Instituto de Tecnologia Agricola e Alimentar (ITAA) in Rio de Janeiro.

There is no question that cassava can be processed and fortified to meet the nutritional needs of both humans and animals. However, the engineering technology needed for developing processing plants does not exist at present in many of the developing countries nor is there generally a constant supply of quality roots. The cassava processing industry is plagued with inadequate supply, poor utilization of the by-products and lack of highly trained technicians at both the farm and industrial level. Government support prices, where available, are far too low to be an effective incentive for increased production. Land, labor and production technology are generally available but very little has been accomplished in molding these into a cohesive economic unit with the main objective of providing a constant supply of raw material from the farmer to the processor for processing.

The cassava starch industry also has its problems. Unlike processors of cereal starches who depend heavily on by-products and modified products, the cassava industry today has very little work underway to produce modified or derived products and consequently has developed relatively few by-products. Thus, if it is to compete in the world market, it will have to depend heavily on producing starch alone. At present, the starch that is produced cannot replace completely the cereal starches used in

baking, brewing, etc., but considerable monetary gains could be realized if cassava starch could be substituted for cereal starches in these industries. This appears to be feasible since it is being practiced with considerable success in certain countries. However, in a cassava starch industry, quality control will be a very important factor. Also, a strong marketing organization must be formed and research will be needed on new uses, products and markets. The advantages of cassava starch should be explored instead of trying to compete with the cereal starches for the same markets and uses.

RECOMMENDED RESEARCH

The following recommendations for research are presented for consideration. No attempt has been made to delineate the details of the research but only to outline the broad general areas needing attention.

Production Research:

An active agronomic research program on cassava is feasible and should be initiated and funded as soon as possible. The primary objective of the program would be to increase yields/ha economically.

Considerable emphasis should be placed on seedbed preparation, weed control, fertility maintenance and on soil and water management practices required on dry or droughty soils. Attention should be given to the relationship between essential elements in the soil solution and yield. An over- or under-supply will result in reduced yields. A continuous supply in dilute solution is essential and therefore slow release fertilizers should be incorporated into the research and management program.

Research emphasis should also be placed on determining the soil moisture requirement, soil pH, nutrient requirements, and stand density on the better cultivars in each of the 3 continents of the world in which cassava is grown. The cost of production in terms of planting, weeding, insect and disease control, and harvesting should be tabulated in cooperation with an economist and efforts made to reduce production cost to the point where cassava can be produced for processing of starch or chips for local use and/or export for utilization by humans or in animal feeds.

Breeding:

Both short- and long-term breeding programs should be considered with the objective of developing varieties with higher yields, protein and starch content, quality, resistance to insect and diseases (particularly viruses), low HCN content, more drought resistance and extended keeping quality following harvest. Furthermore, consideration should be given to selecting for a high foliage producing variety for making silage and leaf meal for livestock feed.

It is further suggested that consideration be given to establishing cassava germ plasm banks on each of the three continents (Africa, South America, Asia). These banks should preferably be established under the direction of an internationally funded institution whose overall administration and funding is provided by the organization which is the least susceptible to changes in national policy. This would insure adequate and long-term support which is essential. Financing should be provided through a multi-lateral effort of AID, the Rockefeller, Ford and Kellogg Foundations, FAO, UNDP, IBRD, Developed Nations, etc.

At each of these centers, all existing varieties obtainable would be collected, classified by morphological characteristics, nutrient content and indexed for viruses and maintained virus free.

These plant material banks would serve as a source of germ plasm for breeders and producers throughout the world and provide a uniform method of classification to reduce duplication, even though some duplication is highly advisable to determine performance under different environmental conditions. What is meant here is more than a routine variety collection. The centers should cooperate with or be established at such centers as CIAT, IITA and possibly at the newly proposed International Vegetable Improvement Center at Taiwan, IRRI in the Philippines or at one of the regional Thailand stations. Plantings should be made in such a plot design as to enable efficient evaluation of germ plasm.

Livestock:

A research program should be established to conduct extensive detailed experiments with swine, poultry, cattle and small laboratory animals such as the mouse, vole or rat for rapid screening. The emphasis should be on determining the quality and quantity of cassava in animal diets, especially with the new higher protein varieties. Detailed research will be necessary in the broad categories of feed preparation, ration palatability, and protein, lipid, mineral and vitamin nutrition.

Physiological, Insects and Diseases:

Post-harvest losses due to insects, microorganisms and physiological degradation presently appear to be an obstacle for the long-term commercial storage, marketing and export of cassava and should not be overlooked in the research program. Based on research to date, the practical solution

to these problems appears feasible with limited resources, and the odds for success and the dividends to be expected from such research projects should be very high.

Processing:

Research is needed in facilitating and modernizing cassava processing, fortification of products and new product development for human and animal consumption. Roots having higher vitamin content, such as the yellow fleshed varieties, should be evaluated.

Cassava flour fortified with fish protein concentrate, with soy protein isolate, with torula yeast and with caseinate should be experimentally prepared. The one or two with the highest acceptability value, as determined by taste panels, should be made available for mass feeding to further delineate consumer acceptability. Similarly, a cassava macaroni enriched by using varying proportions of cowpeas, opaque-2 and floury-2 corn, ground nut meal, soybean meal and high protein rice and wheat varieties could be prepared. These same products could be fortified with lysine, methionine and tryptophan. Flours could be improved by adding calcium-stearyl lactyl lactate as a conditioner. Cassava could be used in higher proportions in breads and other bakeries if methods of incorporation were altered, i.e., by mixing for longer periods of time, use of different temperature-time relationships in baking and changing the type of ingredients added. Binding agents such as glyceryl monostearate could be used to provide satisfactory dough and loaf structure.

Research programs need to be initiated in the major universities and experiment stations in many of the developing countries. Personnel

in these institutions should include resident agricultural and home economists and food technologists who can determine satisfactory ways of processing, storing and utilizing cassava so that a product of better and more uniform quality can be assured. In addition, such personnel should be charged with finding new and improved ways of utilizing the fresh root, chips, flour and starch and of getting this information to the people.

Research on methods of rapid detoxification of cassava roots and the use of pure culture and controlled fermentation for the production of gari and/or similar products should be initiated. All processing and new product research should be coordinated with consumer acceptability studies.

Human Nutrition:

Research is needed on the biological value and nutritive ratio of menus in which cassava is the predominant or subsidiary item. Menus of this type should be completely evaluated, not only by proximate analysis, but by actual feeding experiments in which metabolism trials, nitrogen balance studies and possibly isotopic tracer studies with experimental animals are included. There is a definite need for information relating to the utilization of cassava at the cellular level.

Menus and new products in which cassava leaves are utilized should be developed and evaluated by home economists, food technologists and nutritionists.

The health-related aspect of feeding cassava has been inadequately explored. Since fermentation processes do not eliminate all the prussic acid, there is a possibility that residual poison can accumulate in the

body through continued consumption of products made from bitter varieties. Cassava consumption has been implicated with the incidence of goitre in Nigeria but the goitrogenous substance has not been identified or confirmed; therefore, research should be initiated using experimental animals to either verify or refute this belief.

Marketing:

Since production is generally organized in small units both at the farm and processing level cooperative structures for producers and precessors are needed in many countries. Such organization would improve the present marketing system by providing information on market prices and transportation costs and simultaneously give access to bank credit to small operators currently outside the formal credit system. Extension of research results would also be facilitated if producers had a formal organization. Widespread use of grades and standards would facilitate trade between distant market centers by reducing uncertainty of product quality.

Economic Inputs:

Although the need for economic data is referred to in various sections above, a more clear-cut description is needed. This description is presented below under the following subheads.

Production.--Considerable work needs to be conducted on production input-output data. For example, the relative merits of the costs of the traditional (human power) production methods should be compared to production techniques of partial or complete mechanization (including machine and animal power). The goal is to lower the economic costs of manpower requirements in land preparation, planting, fertilizing,

cultivation and harvesting. Harvesting techniques, per se, must be critically examined to determine the relative merits of complete versus partial harvesting, harvesting of stems and leaves for livestock feed (which lowers root production) and what part or parts of the plant should be partially harvested.

The economics of fertilizer inputs should be determined. Methods need deriving to achieve quantity discounts, what analysis of fertilizer is needed (to fit local conditions), and how to lower transportation and distribution costs.

Credit is usually always necessary if modern inputs are utilized. Therefore, the best methods of obtaining financing, terms, etc., needs determining for such items as machinery, animal power and fertilizers.

New Products.--While efforts are being made to develop new products such as canned or dried slices, French fried slices and/or fried chips, cassava macaroni, paste and powders, the economics of manufacturing, distribution and marketing methods and measurement of market potentials should be conducted.

Animal Feeds.--The economic costs and returns of varying inputs of cassava components (roots, stems, leaves) and protein mixes for all kinds of animals including beef, dairy, pigs and chickens under existing price-value relationships in each country should be determined.

Processing.--The market potential for fortified cassava flour needs to be determined. This will involve analysis of costs of fortifying. The place or places of fortifying and best methods of distribution must be specified. Methods of developing consumer acceptance is of prime importance.

Generally throughout the tropics, cassava is processed for flour or gari in small family type plants. These plants require only small production units (25 hectares or less) to support their annual output. A detailed analysis of optimum firm size appears essential. This may require the introduction of some additional machinery (which in turn leads to some industry). Product flows should be developed using work simplification techniques. Technical assistance must be made available in planning, designing and operating flour mills.

Expansion of the processing of starch, chips and flour for export appears to have limited potential in many countries until yields per hectare increase and/or production costs per kilo are decreased. As these things occur, aid in planning, designing, and operating specialized mills will be required.

Assembly, Transportation and Distribution.--Individual transportation models need to be developed in the developing countries to determine the value of existing highways on assembly, transportation and distribution costs and the projected supply responses of farmers to improvement of these conditions. This is true for both raw product (roots) and finished product (flour).

Other.--Methods must be devised for obtaining and disseminating market news of value to farmers.

Acceptable, workable grades and standards for flour and other products need to be developed. Methods of implementing these grades and standards should be devised.

Forecasting of retail and farm prices should be initiated. This advisory service would aid in removing some of the supply fluctuations.

Realistic guaranteed price support at the farmer level would be most helpful.

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