CURRENT TRENDS IN CASSAVA RESEARCH

B.L. Nestel*

SUMMARY

Cassava, for long a crop neglected by research workers is now receiving attention at both national and international research centres with the largest ever research programme for this commodity being provided by the International Centre for Tropical Agriculture (CIAT) in Colombia. The significance of the crop in tropical agriculture and its growth potential, especially as an animal feed, have recently been widely recognized. The recent literature, and a substantial volume of unpublished ongoing work, are reviewed under the following headings: cassava as human and animal food: enrichment and fortification: toxicity: industrial use: economics of production: genetic improvement: diseases and pests: factors affecting yield: and improved information systems. A multi-disciplinary approach to cassava research and a greater research input are recommended.

RESUME

Le manioc, une culture oublié pendant des années par les investigateurs, recoit actuellement une attention particulière de la part des centres de recherches nationaux et internationaux; jusqu'a présent, le plus grand programme d'investigation sur le manioc se fait au Centre International pour l'Agriculture Tropical (CIAT) en Colombie. Il n'a eté que tout récemment qu'on a reconnue la valeur de cette culture dans les pays tropicaux et sa capacité de production, comme nourriture pour animaux spécialement. Des publications récentes et de nombreaux travaux actuellement en procés et qui n'ont pas encore eté publiés ont eté décrit sous le titre: "Le manioc comme nourriture humaine et animal, sone enrichissement et renforcement, toxicité, utilization industrielle, economie de sa production, progrès génétique, maladies, pestes, facteurs qu'affectent son rendement et des méthodes meilleurs d'information". On recommend l'utilization d'un plus grand effort investigatif et un apercu multidisciplinaire dans l'investigation sur le manioc.

RESUMEN

La mandioca, un cultivo olvidado durante mucho tiempo por los investigadores, ha despertado ultimamente el interés de los centros de investigación tanto a nivel necional como internacional; hasta ahora el mayor de los programas de investigación sobre este cultivo se está llevando a cabo en el Centro Internacional de Agricultura Tropical (CIAT) en Colombia. Solo recientemente ha sido reconociao el valor de su cultivo en los trópicos y su capacidad de producción, especialmente como alimento para animales. Un recuento de las publicaciones recientes y de una cantidad apreciable de trabajo actualmente en desarrollo que no ha sido publicado, aparece bajo el título: "La mandioca como alimenta para humanos y animales, su enriquecimiento y fortalecimiento, toxicidad, utilización en la indstria, economiá de su producción, mejoramiento genético, enfermedades 6 pestes, factores que afectan su rendimiento y sistemas mejorados de información." Se recomienda un jayor esfuerzo investigativo y un enfoque multi-disciplinario en la investigación sobre mandioca.

INTRODUCTION

One of the most thoughtful and perceptive contributions to the Second International Symposium on Tropical Root Crops in Hawaii was presented by Frank Martin[115] in his paper entitled 'Cassava in the World of Tomorrow'. Martin postulated that cassava represented an untapped resource in tropical agriculture and indicated what he felt was the type of research programme required before the potential of this commodity could be properly assessed and exploited. In some senses Martin's paper turned out to be prophetic in that within a year of its presentation, the International Centres for Tropical Agriculture in Colombia (CIAT) and Nigeria (IITA) both decided to give priority to cassava in their research programmes.

Prior to 1971 the global resources available for cassava research were extremely limited and, with the exception of Kerala in India, the work was being carried out by individual scientists, usually with limited financial support, rather than by multidisciplinary teams. In the last two years this picture has changed

*International Development Research Centre, Latin American Regional Office, Apartado Aereo 53016, Bogota, Colombia.

dramatically. CIAT now has a team of scientists from nine different disciplines backed up by basic research in Canada, and dealing with eight specific problems. The total annual budget of this joint programme exceeds one million dollars. The new multimillion dollar research and training centre at CIAT is already receiving scientists for training, especially in methodology, not only from Latin America but also from Asia and Africa. Thus, the framework has been established for constructing an international network of cassava researchers somewhat analogous to that which already exists for wheat and rice.

CIAT is fortunate in that Latin America is free from the problem of mosaic disease which causes serious losses in Africa. IITA's cassava programme is designed to work specifically on this problem through the disciplines of breeding, entomology and pathology with subsidiary support from other scientists and network links into other African countries. Like CIAT, with which it has close links, this institution has superb research and training facilities and is able to devote more resources to cassava than have hitherto been available in Africa.

However, while the resources of international centres can do much in the way of basic and applied research and training, their impact on farm productivity ultimately has to be transmitted via national institutions, which have traditionally paid very little attention to cassava except in India, where for the last decade there has been a strong Central Root and Tuber Crop Research Station, albeit with a rather small budget. Fortunately other good new national programmes are beginning to emerge. One of the newest and largest is in North East Brazil where there is a particularly broad-based and dynamic multidisciplinary team at the University of Bahia[5] funded by the private sector and counselled by Normanha. Stronger (and in most cases new) national programmes are also under discussion in Peru, Malaysia and Thailand and in some African countries. Additionally, the private sector (Brascan in Brazil, Uniroyal in Indonesia and Nusbaum Associates) are beginning to look at the potential of this crop.

To a group such as this, it is not necessary to detail the reasons for this upsurge of interest in cassava. Probably the most important factor is the development of the export market for chips and pellets which is now worth about $80 m a year. However, the potential for growth in this market and the likely increase in the use of cassava for food[146], coupled with the general lack of knowledge about the crop in spite of its phenomenal energy producing potential[36] in a hungry world, appear to have led to some rethinking regarding the role of cassava.

During the last two years, I have been associated with the management of research funds specially allocated for cassava, and it has been my fortune to travel extensively throughout the tropical world and to visit many of the relatively small groups of researchers interested in this crop. In my paper today I have attempted to present an overall assessment of the research situation as it is today. The rather ambitious title of this paper is not meant to signify that it is a definitive description of the 'status quo' – there are a number of cassava research workers whom I have yet to meet and I had not seen all of the papers presented at this Symposium when I prepared this paper. The objective of the paper is to provoke discussion on priorities and to stimulate the provision of information on unpublished and current research activities.

I have deliberately biased my presentation towards the utilization side for two reasons. Firstly, because almost all the papers at this Symposium dealing with cassava are production-oriented and, from the formal and informal discussions this week, many of you will already be well-briefed on the agricultural aspects of the commodity. My second reason for stressing utilization is that I have the distinct impression that we are going to see the possibility of higher yields being demonstrated within a relatively short time. However, unless these yields can be produced, stored, dried, marketed and effectively utilized at competitive prices, we may find ourselves, because of the very perishable nature of cassava, with even greater problems than occurred when the 'green revolution' passed its 'take-off' stage.

CASSAVA AS A HUMAN FOOD

Traditonal products

The most important use of cassava is for human food. Whilst data on this are notoriously unreliable their quality does appear to be steadily improving. Current FAO estimates indicate that about 55 million tons out of annual global production of 98 million tons are consumed by humans. Phillips[146] has projected that by 1980 consumption will rise to about 71 million tons.

Table 1 indicates those countries in which human cassava intakes appeared to be highest in the mid 1970's. These national data do disguise regional differences within countries. For example Nicol[134] found that 25–56% of dietary calories in Southern Nigeria came from cassava (as opposed to a national figure of 15% in Table 1). Likewise, as opposed to the Indonesia figure of 15% in Table 1. Bailey's[12] surveys in Java indicated areas where the calorie intake from cassava exceed 63 percent. Normanha[135] recorded urban intakes of 42 kg/caput and rural ones of 200 kg/caput to give a national average intake of 124 kg in Brazil in the early 1960's.

The form in which cassava is consumed is very varied and traditional processing procedures may be very complex[35]. They are also frequently labour intensive, and recently a process has been developed for mechanizing the processing of gari, one of the most popular forms in which fermented cassava is consumed in West Africa[3]. A preliminary report from Ghana[49] indicates that the mechanized gari has high consumer acceptability. Gari production is, however, an important source of employment and a study is presently underway at the University of Ife to examine the socio-economic implications of mechanizing this traditional process.

At the Food Research Institute in Ghana an 'instant' fufu powder has been developed and is being commercially produced[49]. Miche[118] has pointed out that the industrial manufacture of traditional African dishes will not only encounter all the classic difficulties met by the development of agro-industry in the tropics but will also have to build on a raw material which has not yet been the subject of extensive research. He suggested that it will be necessary to develop roots of uniform, simple shape with a thin skin, high dry matter content, high degree of consumer acceptability and good storage potential. A number of these characteristics have been identified in the CIAT cultivar collection (and this issue is also discussed in the paper by Onochie and Makanjuola[140]), but much still remains to be done to incorporate them into a high yielding ideotype.

Some promising progress has been made in storage, for which the litreature has recently been reviewed by Ingram and Humphries[90]. They refer to both early experiences, and to more recent work carried out in India and Venezuela using low temperature storage. Reference is also made to preservation by waxing, a technique which has recently received some publicity in Colombia[8] where it is claimed to have considerably extended shelf life.

More recently, Booth[17] has reported on a technique which extends both post-harvest on-farm storage and shelf-life. In another paper[18], Booth has stressed the importance of mechanical damage in post-harvest losses, thus confirming the observation of Averre[9] that vascular streaking of cassava roots commenced at cut surfaces. Averre's claims[9,10] that vascular streaking is enzymatic in nature received some support from the identification by Czyhrinciw[38] of peroxidase and catalase in fresh cassava. Montaldo[122], suggested that factors other than enzymes might be associated with vascular streaking, and noted some varietal resistance to this condition. Further work on this subject appears warranted.

Enriched and fortified cassava products

Because of its low protein content the nutritional enrichment of cassava has received a great deal of attention. Some work has been carried out on enriching traditional products such as gari[2] and cassava soups and porridges[124]; however, the main attention has been given to fortification of cassava flour with soy protein isolates or soya grits. This work has been the subject of extensive research in Brazil[6] where cassava flour is widely used in the production of composite flours as substitutes for wheat flours. USAID are also supporting studies on fortified cassava in Nigeria and Zaire. At present the problem of using fortified cassava flour appears to be more of economics than of technology in that the protein deficient sector of the population seldom has the cash to purchase flour of any type.

The subject of composite flours has received attention from the Institute for Cereals, Flour and Bread (TNO) at Wageningen in Holland, the Central Food Technological Research Institute at Mysore in India, the Instituto de Technologĩa Agrĩcola e Alimentar in Rio de Janeiro and the Instituto de Investigaciones Technológicas in Bogotá. The subject was exhaustively reviewed at a meeting sponsored by the Study Group on Composite Flours of the International Association for Cereal Chemistry in Bogotá in October 1972. During the last decade remarkable progress appears to have been made in the use of non-wheat flours and starches (particularly cassava) as total or partial substitutes for wheat flour in bread making[97,147,145,45].

This process not only dilutes the gluten but also changes the concentration and characteristics of other components which affect the bread making properties of the mixture. The role of non-wheat starches and their effect on dough quality has recently been reported on by Hoseney *et al.*[83] and the role of gluten substitutes has been examined by Lagendijk and Pennings[101] and by Rasper, Mak and de Man[153] who have studied the structural development of dough and its visco-elastic properties in cassava fortified mixes. Research in progress in Manitoba by Bushuk[22] is showing promising progress towards the development of a simple process of mechanical mixing which both simplified and improves the quality of the flour containing cassava. Technical and economic issues still remain to be resolved, but present and projected demands and the relative prices for wheat and cassava suggest that cassava-fortified flours may play an increasingly significant role in commercial baking in the future.

Using cassava as a substrate for the production of fungal protein was discussed by Gray and Abou-El-Seoud[73], and later expanded upon by Stanton and Wallbridge[174]. More recently Strasser, Abbott and Battey[175] described a pilot plant process for which they prepared preliminary cost estimates for a 10 ton/day plant. Gregory and Reade[74] have developed a process using an *Aspergillus* sp. which grows on a liquid cassava substrate at a temperature of 50°C and at a pH of 3.5. This process appears to have a potential for producing animal feed of 15% protein content form cassava at a relatively low cost under conditions which may be practical at a field scale in cassava producing areas. Related work is being undertaken by Hutagalung and Stanton in Malaysia using a solid cassava substrate.

CASSAVA AS AN ANIMAL FEED

Although early work on fungal enrichment of cassava was related to the need to improve human protein intakes, current activities in this field tend to be more oriented towards livestock feed. The work of Gregory and Reade is particularly related to the use of residues from cassava (tapioca) starch factories[74]. These residues are already used extensively as pig feed. The magnitude of this practice is difficult to estimate in the absence of data on cassava starch production, although Mahendranathan[111] calculated that the production of starch factory residues in Malaysia totalled about 300,000 tons per annum. Obviously a means of raising the protein level of this residue from 2 to 15 percent could have important implications for the pig industry.

The main thrust of work on livestock feeding with cassava is, however, based on the use of raw or dried roots. Preliminary work on this was carried out in the 1930's in Malaya although the modern literature appears to originate from the paper by Oyenuga and Opeke[142] and more recently the work has been spearheaded by Maner and his associates at CIAT[114], by a group of workers at the University of Malaya and by Müller in Singapore[126,127].

Much of this research is being done in countries that are not major cassava producers in world terms. Furthermore, the major current users of cassava in animal feeds are feed compounders in the EEC who import much of their cassava from Thailand where it is seldom fed to either man or livestock. European use of cassava in animal feeds has resulted from its favourable price, compared with that of feed grains, in countries deficient in feed energy. At present cassava seldom comprises more than 10 percent of compounded feeds, although on occasion it has been used at levels as high as 40%, and in some of the tropical trials its level has reached 60 percent. The real potential for using cassava for animal feed appears to lie in cassava producing countries especially those in which the pressure of demand is leading to increasing prices for animal products and where a market for quality meat is developing.

Müller, Chou and Choo[126] found that cassava meal substituted satisfactorily for corn up to levels of 60 percent in broiler rations, provided that the diet was balanced, and that at higher levels of substitution, the cassava was pelletized. Nutritional problems arose if the fibre content of the cassava meal exceeded 3.5 percent and economic difficulties occurred if the cassava meal price exceeded 67 percent of the price of corn. Somewhat similar findings were reported in Mexico by Tejada de Hernández and Brambila[178] who were able to use up to 50 percent cassava meal in rations for young chicks. These had similar growth but lower feed efficiency than chicks on corn starch. The authors commented on the wide range of cyanide levels present in their rations and their uncertainty regarding the nutritional significance of cyanide. A similar finding of satisfactory growth but low conversion efficiency was reported by Jalaludin and Oh[93] who fed very high levels of cyanide to laying hens without producing obviously toxic effects.

Hamid and Jalaludin[78] used cassava successfully to replace corn at levels of up to 60 percent for layers. At higher levels they had difficulty in maintaining the protein content of the ration. Yolk colour became progressively whiter as cassava levels increased, so that a rich source of carotene needed to be added to the ration. There was also some evidence that methionine became a limiting nutritional factor on high cassava rations. The carotene level might, however, be of less significance in areas where yellow cassava is produced[76].

The use of cassava root meal in both grower and layer diets has been reported from Hawaii[54] where egg production, feed conversion, egg weight and shell thickness have been related to levels of cassava intake.

In swine, the most comprehensive work has been carried out by the CIAT workers[112] who have used up to 60 percent cassava in their rations. However, at this level, gain and efficiency declined although these could be improved by methionine supplementation which compensated for the low methionine level of the cassava and also provided a sulphur donor for cyanide detoxification. Hew and Hutagalung[81] found that feed intake in swine decreased as the cassava level of the ration was increased. Performance improved significantly following the addition of 0.2 percent methionine to a 50 percent cassava diet, but did not improve with higher methionine levels. The further addition of palm oil (which also enabled the pigs to better utilize higher methionine levels) and glucose (which may have reduced cyanide levels by forming glyconohydrin and improving palatability) improved both daily gain and food conversion. From the economic standpoint, the fully supplemented 50 percent cassava ration gave 10 percent lower daily gains at a cost per kg. of gain that was 3 percent less than a corn-based ration.

Müller, Chou, Nah and Tan[126] recommended the use of cassava meal in pig rations when the price of a 85 percent cassava, 15 percent soya meal was significantly cheaper than that of corn. They stressed the importance of pelleting the cassava to avoid bulk and dust problems, and the need to balance fibre, mineral, vitamin B and amino-acid levels. Suggested maximum levels of cassava meal for starter, grower and finisher rations of different ash and fibre contents were tabulated. These ranged from 0 percent in starter rations with 5 percent fibre, to 75 percent in finisher rations of 2.8 percent fibre and containing only cassava, soyabean meal and minerals.

Further recent reports using cassava for swine feeding originate from Fiji[179] and Venezuela[29]. A 40 percent cassava, 29 percent rice bran ration was shown to require the addition of zinc before it would give gains equivalent to a ration in which corn was the primary energy source, although evidence was not provided to indicate whether the cassava or the rice bran was responsible for the reduced availability of zinc[117].

The literature on cassava as a ruminant feed appears to be very sparse, although Chicco *et al.*[28], Shultz *et al.*[167] and Shultz and Chicco[168,169] have carried out extensive studies on the use of cassava in conjunction with urea in both bovines and sheep. In Malagasy, Serres[164] described the use of both cassava roots and leaves as components or rations for intensive finishing of cattle. Serres and Tillon[165] described the production of cassava root silage for pigs (fed at 3 kg/day) and cattle (fed at 5 kg/day). Extensive trials on the use of cassava root silage as a component of swine rations have been conducted by Maner at CIAT[112]. Low protein levels presented a problem, and attempts to raise this by microbial action have not so far been successful[74].

Serre's work on using cassava leaves as cattle feed followed Echandi[51] who sought a substitute for alfalfa meal in Costa Rica. This work has been followed up in chickens and quails by Ross and Enriquez[159] and in pigs by Lee[104] and Lee and Hutagalung[105]. It appears that in both pigs and poultry, 20 percent cassava leaf depressed both liveweight gain and feed conversion, but the addition of sodium thiosulphate, methionine and molasses and/or vegetable oil can partially correct these depressions. Further studies on cyanide content[27] and water soluble protein[66] of cassava leaf have been carried out to help elucidate its nutritional value. Additional work on this seems to be necessary since Juarez[94] reported an annual leaf yield of up to 27,000 kg from two leaf pickings in Peru and preliminary data from more frequent picking in Brazil (Bahia) and Colombia (CIAT) suggest that with appropriate management even higher leaf yields may be feasible. Since leaf protein values are reported to be between 20 and 30 percent on a dry matter basis[156], the possible role of cassava leaves as food or feed may need re-examining. Eggum[52] has already shown that the digestibility of cassava leaf protein in rats was 70—80 percent, although the biological value of the protein was only 44—57 percent. However the addition of methionine to the diet raised the B.V. of the cassava leaf protein to 80 percent. A similar result was obtained by Adrian and Peyrot[1] when adding cassava leaf protein to cereal diets.

CASSAVA TOXICITY

Cyanogenic glucosides and cyanide toxicity

In discussing the use of cassava in animal feeding frequent reference has been made to the subject of toxicity. The cyanogenic glucosides of cassava have been known for some time to be responsible for both acute and chronic toxicity in humans, although the importance of chronic toxicity has been studied extensively only in the last decade. Recent work has indicated not only that high cassava intakes are associated with the incidence of tropical ataxic neuropathy in Africa[141], but that in the presence of marginal iodine and low protein intakes, high cassava diets may potentiate the development of goitre and cretinism[53,61]. Domestic livestock are seldom fed high levels of cassava for prolonged periods, but nevertheless there is evidence to indicate that impaired growth occurs in pigs and poultry on high cassava diets unless these are supplemented with methionine[113].

A recent workshop reviewed the subject of chronic cassava toxicity. This covered the biosynthesis of the cyanogenic glucosides[23,34,130], the agronomic and physiological aspects of cassava toxicity[42], and detoxification mechanisms[35,138]. The workshop proceedings[133] contain 18 papers and recommendations for future research. Amongst these was the need to ensure that breeding for low cyanide cultivars would not consequentially increase susceptibility to pathogens and pests. The techniques and problems of adequate assay also received considerable attention. Cyanide in cassava results from the breakdown of the relatively stable glucosides linamarin and lotaustralin, whose own toxicity is unknown. There have been several recent papers[62,161,191] dealing with cyanogen assay in cassava roots and leaves. The relevance of rapid assay techniques to the problem of toxicity requires further clarification, especially since both CIAT and IITA are selecting for low cyanogen levels.

Aflatoxicity

Cassava has also been incriminated in problems of alfatoxicity since it appears to be an excellent growth medium for *Aspergillus flavus*. Samples of cassava flour from Brazil were found to have relatively high levels of aflatoxins and at one time it was thought that this might be associated with the high incidence of black fever in children on the upper Amazon[19]. More extensive studies with cassava starch in Thailand and Hong Kong[166] and in fermented cassava from Dahomey[180] have also shown the presence of aflatoxins and an aflatoxin-like factor has been recorded in India[128]. In a field study in Uganda[163] there was circumstantial evidence that a highly contaminated cassava sample may have been involved in a documented poisoning episode. However, by and large, particularly in view of the varied ways in which cassava is handled after harvest, there appears to be little evidence that aflatoxins present a significant problem.

THE INDUSTRIAL USE OF CASSAVA

Apart from its use as direct food and feed, cassava is used in the food industry, principally in the form of starch. The low-amylase high-amylopectin content of cassava starch give it unusual viscosity characteristics and great dimensional strength, these find a number of specialized uses[11]. The characteristics and behaviour of this starch have been studied in great detail by Rasper[150,152,152], Banks *et al.*[13], Srivasta and Patel[173] Velikaya and Nguen[182], and by a number of Brazilian workers[123,158].

Cassava can be hydrolized to produce glucose[143] and a feasibility study for a cassava based glucose industry has been carried out in Nigeria[47]. It can also be converted to alcohol[177], although this process does not appear to be used industrially.

Dextrins made from cassava flour can be used to make adhesives which are superior to starch-based adhesives in a number of characteristics[63]. Cassava stalks have also been used to make particle board[65].

The technology for processing cassava has been described in some details by Grace[71]. Usually the processing procedures used are very traditional, although some modernization of the cassava starch industry has taken place recently. The last two years have also seen an interest in improving the drying of cassava chips. A simple solar heat drier suitable for cassava was described by Williams, Beeny and Webb[188] and a pilot solar drier of another type is currently undergoing tests in Trinidad[172]. The drying characteristics of cassava are also being studied by Roa[155] who has developed machinery for producing cassavabars (1 x 1 x 0.5 cm) directly from roots. However, none of these new techniques appear to have been evaluated economically in comparison with current drying practices in which sun drying in concrete yards are normal. A variety of chip sizes and shapes are produced and there appears to be an urgent need for further research on the optimum size and shape of chips and perhaps on a simple technology to reduce radiation losses in drying yards.

This need for improvement in current drying and pressing techniques was stressed in a study by Mathot[116] which pointed out that these procedures could lead to substantial improvements in both quality and cost price of pellets exported from Thailand (which supplies the bulk of world trade in this item).

THE ECONOMICS OF CASSAVA PRODUCTION

In order to exploit the markets for cassava, it has to be sold at a price that is competitive. To some degree this depends on the use to which the crop is put. Thus the Thai farmer, who grows most of the cassava which reaches the world market, obtains U.S. $11–12 for the farm-dried chips produced from a ton of fresh cassava, whereas for fresh cassava for human use, the Jamaican farmer obtains 2–4 times this price[147] and, at certain times of the year, the Colombian farmer may obtain 6–10 times the price obtained by his Thai counterpart. However, generally speaking the farm price seems to lie in the range of U.S. $10–15/ton of fresh root equivalent.

It is difficult to cost cassava production since the main inputs are family labour and land, and in subsistence farming areas, the land is often communally owned. Brannen[20] reviewed some of the literature on production costs and found that the usual cost of producing cassava was about U.S. $6/ton. The major production cost was labour. For a variety of reasons, it is difficult to compare the various labour costings available, but in various surveys the man-hours used to produce a ton of cassava appeared to range from 30–200 and to average about 100[4,147,20,48]. Obviously the return to labour from cassava production is very low, notwithstanding the fact that Raeburn *et al.* found the yield per man-day from cassava production exceeded that of other tropical staples. Clarke and Haswell[31] reported a similar finding when comparing both the output value and the labour productivity of various tropical crops in terms of FAO standard wheat equivalents.

The low return to labour relates to the fact that the opportunity costs of labour in many subsistence areas is often regarded as being close to zero, otherwise a production cost per ton of U.S. $6 would not be possible. However, we may anticipate that some mechanization may be necessary in the future since, as economies develop, labour generally tends to demand a higher return, especially for an unpleasant job such as harvesting cassava (which commonly accounts for 25–30 percent of the total labour costs). For this reason production costs maybe expected to rise. Against this it must be taken into account that subsistence yields are often only about 10 percent of the production potential of the crop, so that there is a great deal of scope for reducing the costs of production by raising yields. This is especially true if high-yielding cultivars can be produced that are more easily harvested (by either man or machine) but still retain adequate drought and disease tolerance.

In view of the limited past resources devoted to both the breeding and the mechanization of cassava, compared with those now available, it is difficult to make any forecasts of the likely future pattern of production costs. What does appear probable is that these costs will be strongly influenced by the results of plant breeding work in terms of the achievements that are made with respect to yield and morphology.

Andersen and Diaz[4] have examined this situation from the standpoint of public policy and have drawn particular attention to a possible conflict arising between the social objective of employment-creation and the profit-maximizing objective of introducing new technology. They point out the labour-intensive nature of cassava production and the adverse effects on employment which could arise from both extensive mechanization of land preparation and the widespread use of chemical herbicides. The impact of mechanization on the labour requirements for planting and harvesting has also been examined by Krochmal[99] and the economics of mechanization by Dulong[50] who claimed that very high yield levels would be required for mechanization to become economic in the Malagasy Republic.

Andersen and Diaz's paper[4] highlights the need for more information on the total economic structure of the cassava industry. The global market for animal feed has been looked at by the International Trade Centre[92] and by Phillips[146] and the processing sector in general by Grace[71] and more specifically in West Malaysia by Wahby and Eriksen[184] and in the Malaysian State of Perak by Chye and Loh[30]. However, integrated studies dealing with production, processing and marketing are harder to come by. The Ministry of Agriculture in Thailand completed such a study in 1973 but to date, I believe, it is only available in Thai. A similar type of study is being pursued in Brazil by the Comissao Nacional de Mandioca and by Dantas[39] in the Brazilian State of Bahia. Probably the most complete study of the cassava industry at the national level is a recent Ph.D. Thesis by Tan[176] in Malaysia.

At the farm level, Diaz[46] has published a preliminary report on a 300 farm survey in 5 zones of Colombia. This survey is attempting to provide very detailed information on production practices and to relate these to the CIAT research programme. Some farm costing studies involving cassava are also being carried out at IITA and by the team at the University of Bahia. However, the absence of adequate economic data would appear to be a constraint from the standpoint both of identifying growth opportunities and attracting new investments. In this context it is relevant to observe that cassava does appear to offer opportunities for labour-intensive production on small farms and since small farms and rural employment are important issues in many tropical countries, the need for more research on the structure of production and the relationship of this to public policy cannot be overstressed.

THE GENETIC IMPROVEMENT OF CASSAVA

Even in the absence of detailed agro-economic studies, the cassava breeder does have some guidelines. Foremost amongst these is the need to evaluate the genetic material which is currently available. To date very limited attention has been paid to the study of fundamental aspects of the genetics, cytology and breeding of the crop. Little has been added to the literature in these fields recently, the current state of knowledge has been covered in the review of Dempsey[44] and in the reports to the previous and current Tropical Root Crop Symposia by Magoon[107,108] and Magoon and Krishnan[110].

The main efforts in plant breeding are devoted to increasing yield, although both CIAT and IITA are screening for cyanogen level and for disease and insect resistance. Plant breeders working with cassava are known to be operational in Brazil, Colombia, Costa Rica, India, the Malagasy Republic and Nigeria, although the number of trained geneticists involved with the crop is still very small. The use of radiation or mutagenic agents has been practiced in Turrialba (Costa Rica), and Malagasy Republic[50] and India, where it has been associated with efforts to enhance the protein level of the crop[84]. Colchicine has also been used to induce polyploidy by Magoon *et al.*[109] and later by Imam[86], but significant yield increases do not appear to have followed this treatment.

The recent publication by Rogers and Appan[157] of a monograph on the genus *Manihot* is useful for both agronomists and plant breeders interested in cassava improvement. Their bio-systematic work has identified some particularly interesting opportunities for further research in interspecific hybridization which has already been used successfully to produce disease resistance in cassava. In Java, grafts of *M. glaziovii* on *M. esculenta* stock have been found to lead to the production of enormous roots (up to 100 kg in 24 months) on individual plants, but whether or not this technique has a potential beyond 'backyard' production remains to be determined[43]. Similar but less spectacular increases in yield have been reported from grafting *M. flabellifolia* onto *M. esculenta*, although, according to Rogers and Appan[157], *M. flabellifolia* is the same species as *M. esculenta*.

A recent upsurge of interest in the ethnobotany of cassava may also be of interest to the plant breeder. The role of cassava in the development of civilization in lowland South America was discussed at a Symposium of the American Anthropological Society in November 1971 at which it was postulated that the use of manioc (cassava) may pre-date that of corn. Other evidence concerning the area of origin of *M. esculenta* as a crop plant has been reviewed by Renvoize[154].

A major problem associated with efforts to select and improve cassava is the difficulty that is faced in moving material around the world because of disease problems. The normal method of propagation by vegetative means accentuates this problem, as does the outbreeding nature of the plant (due to protogyny) and the frequency with which pollen sterility occurs. Efforts to overcome this situation are being made by propagation studies[99,185].

Wholey and Cock have developed a field multiplication procedure which enables them to produce 1800 stem cuttings from one plant in one year. Under mist propagation in a greenhouse, they have increased this number to 18000 cuttings from one mature plant. Another possible approach to rapid propagation is through tissue or cell culture. This is being developed primarily to produce mosaic-free plants[16,95], but may also offer possibilities for rapid propagation (and perhaps for the production and dissemination of mosaic-free material) provided that the genetic stability of culture material can be assured.

DISEASES AND PESTS OF CASSAVA

Mosaic disease in cassava has been the subject of a number of recent studies and the state of current knowledge was reviewed at a Workshop held at IITA in December 1972[91]. This meeting categorized cassava 'mosaics' into:

a) a mechanically transmitted disease found in Brazil whose causal agent is a virus of the potato virus X group.
b) a white-fly transmitted disease found in Africa and India whose causal agent is unknown.
c) mycoplasm-induced diseases, of which at least three occur in Brazil and one in the Ivory coast.

The meeting was not attended by anyone familiar with mosaic disease in India and the relationship of this to the African and Brazilian mosaics does not appear to have been studied although Peterson in Canada[144] has recently established a programme which will enable him to study cassava mosaic diseases from all three geographic sources.

A report on Indian mosaic is being presented at this meeting by Narasimhan and Arjunan[129] and Kitajima and Costa[98] are reporting on their EM studies with cassava virus and mycoplasms in Brazil. The IITA report contains a review of most of the African literature but excludes reference to a paper by Golato[70] in Ghana and to the most recent contribution by Chant, Bateman and Bates[25]. It also excludes mention of a paper by Ganguly, Raychaudhuri and Sharma[68] describing a serodiagnostic method for detecting mosaic infected plants in the field. This is a subject which may justify further study in view of the difficulty of ensuring that vegetative material is mosaic-free.

No work on the 'brown streak' virus disease of East Africa appears to have been published recently. However, the literature on the major bacterial, viral and fungal diseases of cassava has recently been reviewed by Lozano and Booth[106]. Their review in fact covers most of the work reported on at this meeting in addition to many observations from recent research at CIAT. They draw attention to the large number of diseases, many of them poorly understood, which can attack cassava both prior and subsequent to harvesting. Little information is available on control measures except for bacterial blight.

Cultivars which are resistant to some diseases are noted, and the need for more information on host-parasite relations in other better to understand the nature of this resistance is pointed out. A similar plea is put forward by Rosseto *et al.*, and it appears to be relevant to resistance to insects since van Schoonhaven[181] has noted varietal differences in tolerance to attack by thrips and mites. The possibility of relating disease and pest resistance to a chemotaxonomic classification of the CIAT and other cultivar collections is being examined by Grant[72].

The literature on parasitic nematodes associated with cassava appears rather sparse. In his bibliography, Montaldo[121] lists only two species recorded as parasites of cassava. There is, however, a recent reference on this subject from Trinidad[21]. An up-to-date review of insect and mite pests of cassava also appears to be lacking although Montaldo lists about ninety species of insect pests as having been found on cassava. Currently detailed work on thrips and spider mites is under way at CIAT. In Uganda the accidental introduction of a neotropical mite, *Mononychellus tanajoa* (Bondar) is causing considerable devastation[15] and the mite is being studied by Nyiira[136].

Research on weed control in cassava also appears to be relatively new. Doll and Piedrahita[48] at CIAT have a fairly comprehensive programme which is of particular interest from the standpoint of the relationships between morphology, yield and weed control. Their programme is linked to the cost studies of Andersen and Diaz referred to previously. Doll's work highlights the need for a multidisciplinary approach to cassava research, in which the definition of the ideotype which the plant breeder must seek may be dependent not only on yield but on factors such as disease and insect resistance, weeding costs, ease of harvesting, drought tolerance, fertilizer response, cyanide level, starch composition, etc. The complexities of these interrelationships may imply the necessity for some model-building inputs, once more information is available on the basic production parameters.

FACTORS AFFECTING YIELD

It is in these production parameters, particularly 'yield' that the major research thrust is taking place at present. This is hardly surprising since yields under farm conditions are frequently reported as averaging only 5–15 tons/ha whereas experimentally it has been claimed that this range can be far surpassed. Dulong[50] reports 70 tons/ha in the Malagasy Republic, Cock[33] 47 tons in Colombia, and Schmidt and Pereira[162] 34 tons in Brazil. These yields are well in excess of those encountered under commercial conditions, although on a recent visit to Malaysia I witnessed the harvesting of a crop on virgin land which was estimated as yielding over 50 tons/ha, and I understand from Chan that this is not unusual. At this meeting we have reports on yield responses to various fertilizers from Sierra Leone[75], Kenya[77], Peru[82], Nigeria[137 139] and Colombia[185], and recent papers on this theme also originate from the Seychelles[171], Mozambique[125] and Malaysia[24].

Amongst the factors influencing yield, one that has been relatively neglected in past research efforts is that of the onset and rate of tuber root bulking. Wholey and Cock found that differences in yield after seven months were associated with variations in the rate rather than in the time of onset of bulking. However, seven months may be too early to make decisions on yield maximization. Chan found that a number of his cultivars yielded significantly higher at 12 months (but not at 14) than they did at 8 months. There appear to be very great differences in local practices in relation to harvesting age. This factor must obviously be an important component of any systematic study on yield.

Chan and Okigbo have both studied the effects of planting stick orientation, length, and polarity at planting time on subsequent yield and performance. This is a subject on which the early cassava literature is very rich. There seems to be little consensus on the issue of orientation although most authors seem to get better growth from longer cuttings and to have a fairly high mortality in cuttings planted upside down. Enyi[55] has also shown that there was a positive linear relationship between root yield and age of planted cutting (this is a subject that may justify re-examination within the context of the rapid propagation technique of Wholey and Cock.)

Enyi[56,57,58] has also examined the effects of spacing on growth development and yield of single and multiple shoot plants. He found that bulking rate was positively related to net assimilation rate and that both net assimilation and tuber yield were higher in single shoot plants. Maximum yields were obtained from a planting density of 12,600 plants/ha. (A further report on this is contained in a more recent paper[59] which has not yet come to hand).

The relationship between spacing, yield, assimilation and dry matter distribution has also been examined by Sinha and Nair[170] and Williams[186,187,188] and in papers presented by Cock[32], Cuervo[37], Natarajan and Rengasamy[131] and Natarajan and Vijayakumar[132]. It appears that leaf area index is sub-optimal after six months due to leaf fall although in one cultivar Cock found that he could compensate for this by raising the plant population as high as 20,000/ha and that the improved LAI was associated with increase in yield. However, the application of modern techniques and ideas in plant physiology to cassava research is very new, and there is obviously scope for more research on factors affecting dry matter production especially leaf area index, leaf inclination and photosynthesis.

Research on the responses of cassava to fertilizer has given conflicting and generally unsatisfactory results. It has been suggested that high levels of nitrogen may increase leaf production at the expense of roots[100], and in one experiment[40] P and K applied before planting depressed survival. On the other hand various authors (Chan[24], Chew[26], Cock[32], de Silva and Freire[41], Vijayan and Aiyer[183] and Young[190]) suggest a positive response to fertilizer, especially nitrogen, although this response is not always significant. Research on fertilizer use is currently underway in a number of stations and is also reported on at this symposium by Godfrey-Sam-Aggrey and Gurnah.

More basic studies on the mineral nutrition of cassava have been carried out by Forno, Asher and Edwards[67] in Queensland and by Bates[14] in Canada who is preparing a series of colour slides on macro and minor element deficiency and toxicity symptoms. This work is being carried out at the University of Guelph on behalf of CIAT. A related programme[85] in the growth rooms at Guelph is examining: a) photosynthesis and b) growth and tuberization in *M. esculenta* and some other *Manihot* species. Growth and tuberization are also being studied in the field in Colombia[32], India[87,88], New Guinea[60] and Trinidad[64]. Ketiku and Oyenuga[96] have traced the changes in the carbohydrate constituents of cassava roots during growth. The starch level peaked (81 percent of the carbohydrates) at 8 months and sugars reached their peak concentration of 5.7 percent (of which 69 percent was sucrose) 9 months after planting.

The water requirements of cassava have received little study although it is known to be very drought tolerant. The only paper that I am aware of on this subject is that by Garcia and Montaldo[69] although the group at the University of Bahia are studying the responses of cassava to irrigation.

IMPROVED INFORMATION SYSTEMS

Until recently it has been difficult to track down the literature dealing with cassava, although in the past few years there have been several special bibliographies[121,79,89,7], in addition to some reports with lengthy lists of references[71,80]. However, none of these bibliographies appears to include more than about half of the world literature which is currently believed to exceed 3500 references. An effort is being made to fill this void by preparing a comprehensive bibliography with a key word index and abstract of each item referenced[119]. A cassava thesaurus has been prepared[103] and an interim bibliography with about 1500 abstracts is expected to be published at the end of 1973. When the final document is prepared, hopefully in 1974, CIAT will institute a cassava information centre which will be linked into the AGRIS network and will be able to provide abstracts and photocopies of the world literature to interested workers.

In recent years the literature on cassava has grown by about 50 documents each year. The last two years have seen a remarkable upsurge in these numbers, particularly in 1973, due especially to this meeting (48 papers mention cassava in their title) and to the meeting on cyanide toxicity in cassava (18 papers). In this paper I have mentioned the names of nearly 100 scientists who are actively engaged in research on cassava at the present time.

This is a big change from the situation only three years ago. However, if the world really produces almost one hundred million tons of cassava a year, and if this has a farm value which is normally at least US$10/ton, as my figures suggest, we are talking of a commodity whose annual production value exceeds one thousand million dollars and may reach $1.5 billion. As far as I can judge, the research expenditure devoted to the production side of this industry lies between 2 and 3 million dollars a year, or perhaps 0.25% of the value of production with perhaps 40% of the research funding going to CIAT and related programmes.

Concerning human resources, there appear to be less than ten trained geneticists working full-time on this crop, the number of physiologists and economists may be even smaller. The state of knowledge described in this paper and some of the questions raised suggest that the current research input may still be too low, especially in terms of the value of the crop and its apparent growth potential. Areas requiring more research are numerous but perhaps most important of all is to ensure that more work is performed on an interdisciplinary basis. One has only to study the literature to recognize how limited has been the breadth of past research on cassava and how irrelevant are many of its findings. Hopefully, with the network of cassava researchers and the information services that are developing, we will not see these past mistakes repeated.

REFERENCES

1. Adrian, J. and Peyrot, F. (1971) *Plt. Fds. Hum. Nutr.*, 2, 61.
2. Akinrele, I.A. (1967) *W. Afr. J. Biol. and Appl. Chem.*, 10, 19.
3. Akinrele, I.A., Ero, M.I.O. and Olatunji, F.O. (1971) Fed. Inst. Indust. Res. Tech. Mem 26. Fed. Min. Indust., Lagos, Nigeria.
4. Andersen, P.P. and Diaz, R.O. (1973) Mimeo.*
5. Anon. (1972a) Proyecto Mandioca, Relatório Semestral de Andamento e Avaliacao de Pesquisas, Fed. Univ. Bahia, Salvadore, Brazil.
6. Anon. (1972b) Mimeo Rep. 3rd meeting on fortification of mandioca products, Rio de Janeiro 13–16 March 1972, Min. Agric. Rio de Janeiro, Brazil.
7. Anon. (1972c) Bol. Tec. do Centro de Tec. Agric. e Alimen, No. 1, Min. Agric., Rio de Janeiro, Brazil.
8. Anon. (1973). 'La República', 8 Nov. 1973, Bogotá, Colombia.
9. Averre, C.W. (1967) Proc. Int. Symp. Trop. Root Crops. 2, 31. Univ. W. Indies, Trinidad.
10. ––––– (1970) Mimeo. Reunion Lat.-Amer. Fitotechia, Bogota, Colombia.
11. Ayres, J.C. (1972) In 'Hendershott *et al.*' Chap. VIII (see ref. 80).
12. Bailey, K.V. (1961) *Trop. Georgr. Med.* 13, 234.
13. Banks, W., Geddes, R., Greenwood, C.T. and Jones, I.G. (1972) *Staerke* 24, 245.
14. Bates, T. (1973) Personal communication to IDRC, (Soil Sci, Dept., Univ. Guelph, Canada).
15. Bennett, F.D. (1973) Personal communication, (Comm. Inst. Biol. Control, W. Indies Station, Curepe, Trinidad).
16. Berbee, F.M., Berbee, J.G. and Hildebrandt, A.C. (1973) *In Vitro* 8, 421.
17. Booth, R.H. (1973a) Mimeo.*
18. ––––– (1973b) Proc. 2nd Int. Cong. Plt. Path.
19. Boshell, J. (1968) Belem Virus Lab. Ann. Rep. (Appendix), Belem, Brazil.
20. Brannen, S.J. (1972) In 'Hendershott *et al.*' Chap. X (see ref. 80)

*Paper presented to 3rd Int. Symp. on Trop. Root Crops. Dec. 2–9, 1973, IITA, Ibadan, Nigeria.

21. Brathwaite, C.W.D. (1972) *Plant. Dis. Rep.* 56.

22. Bushuk, U. (1973) Personal communication to IDRC, (Food Sci. Dept. Univ. Manitoba, Canada).

23. Butler, G.W., Reay, P.R. and Tapper, B.A. (1973) In 'Nestel and MacIntyre', p. 65 (see ref. 133).

24. Chan, S.K. (1969) Mimeo. Rep. 'Tapioca Invest. at the Fed. Expt. Sta. Serdang, Min. Agric. Kuala Lumpur, Malaysia.

25. Chant, S.R., Bateman, J.G. and Bates, D.C. (1973) *Trop. Agric.* 48, 263.

26. Chew, M.Y. (1970) *Malay. Agric. J.* 47, 483.

27. —————(1973) *Malay. Agric. J.* 48, 354.

28. Chicco, C.F., Carnevali, A.A., Shultz, E. and Ammerman, C.B. (1971) *Asoc. Lat-Amer. de Prod. Anim, Memoria*

29. Chicco, C.F., Garbati, S.T., Muller-Haye, B. and Vecchionacce, H. (1972) *Agron. Trop. (Maracay)* 22, 599.

30. Chye, K.O. and Loh, W.Y. (1971) *Agric. Econ. Bull.* 1, 1 Fed. Agric. Mkting, Authority, Kuala Lumpur, Malaysia.

31. Clarke, C. and Haswell, M.R. (1964) *The Economics of Subsistence Agriculture.* Macmillan, London.

32. Cock, J.H. (1972a) Mimeo.*

33. ——————(1973b) Personal communication to IDRC (CIAT, Colombia).

34. Conn, E.E. (1973) In 'Nestel and MacIntyre', p. 55 (see ref. 133).

35. Coursey, D.G. (1973) In 'Nestel and MacIntyre', p. 27.

36. Coursey, D.G. and Haynes, P.H. (1970) World Crops 22, 260-5.

37. Cuervo Gomez, P.L. (1973) Mimeo.*

38. Czyhrinciw, N.W. (1969) *Rev. Fac. Agron. (Maracay)* 5, 108.

39. Dantas, W. (1973) Personal communication to IDRC, (Econ. Dept., Univ. Bahia, Salvadore, Brazil.)

40. da Silva, J.R. and Freire, E.S. (1968a) *Bragantia* 27, 291.

41. ——————(1968b) *Bragantia* 27, 357.

42. de Bruijn, G.H. (1973a) In 'Nestel and MacIntyre' p. 43. (see ref. 133).

43. ——————(1973b) Personal communication to IDRC, (Agron. Fac., Univ. Brawijaja, Malang, Java).

44. Dempsey, A.H. (1971) In 'Hendershott *et al.*! Chapter II. (see ref. 80).

45. Dendy, D.A.V., Clarke, P.A. and James, A.W. (1970). *Trop. Sci.* 12, 131.

46. Diaz, R.O. (1973) Mimeo. Descripción agroeconómica del proceso de cultivar yuca en Colombia, CIAT, Colombia.

47. Dina, J.A. and Akinrele, I.A. (1970) Econ. Feas. Study for the Establishment of a glucose industry in Nigeria, Fed. Inst. Indust. Res., Lagos, Nigeria.

48. Doll, J. and Piedrahita, W. (1973) Mimeo*.

49. Dovlo, F.E. (1972) Mimeo. Cassava and cassava prod. Conf. 24/25 March, 1972. Univ. Ghana, Legon, Ghana.

50. Dulong, R. (1971) *Agron. Trop* 26, 791.

51. Echandi, M.O. (1972) *Turrialba* 12, 166.

52. Eggum, B.O. (1970). *Brit. J. Nutr.* 24, 761.

53. Ekpechi, O.L. (1973) In 'Nestel and MacIntyre', p. 39. (see ref. 133).

54. Enriquez, F.Q. and Ross, E. (1972) *Poult. Sci.* 51, 228.

55. Enyi, B.A.C. (1970) *Beitr. trop. and subtrop. Landwirt. and Tropenvet-Med.* 8, 71.

56. ——————(1972a) *East Af. Agric. for. J.* 38, 23.

57. ——————(1972b) *East. Af. agric. for. J.* 38, 27.

58. ------ (1972c) *J. Hort. Sci.* 47, 457.

59. ------ (1973a) *J. Agric. Sci.* 81, 15.

60. ------ (1973b) Mimeo.*

61. Ermans, A.M., van der Velden, M., Kinthaert, J. and Delange, F. (1973) In 'Nestel and MacIntyre' p. 153. (see ref. 133).

62. Esquivel, T.F. and Maravalhas, N. (1973) *J. Agr. Fd. Chem.* 21, 321.

63. Evans, R.B. and Wurzburg, O.B. (1967) In *'Starch Chem. and Tech.'* Vol. 2, p. 253. Ed. Whistler, R.L. Academy Press, New York.

64. Ferguson, T.H. (1973) Personal communication to IDRC. (Dept. Soil Sci., Univ. West Indies, Trinidad)

65. Flaws, L.J. and Palmer, E.R. (1968) Report G34, Trop. Prod. Inst., London.

66. Foo, L.C. and Chew M.Y. (1973) *Malay. Agric. J.* 48, 347.

67. Forno, D.A., Asher, C.J. and Edwards, D.G. (1973) Mimeo.*

68. Ganguly, G., Raychaudhuri, S.P. and Sharma, B.C. (1970). *Curr. Sci.* 39, 191

69. Garcia, B.J. and Montaldo, A. (1971) *Agron. Trop. (Maracay)* 21, 25.

70. Golato, C. (1971) *Riv. Agric. Subtrop. Trop.*

71. Grace, M. (1971) *Processing of cassava,* Agric. Serv. Bull. 8, FAO, Rome.

72. Grant, W.F. (1973) Personal communication to IDRC (Dept. Genetics, McGill Univ. Canada.)

73. Gray, W.D. and Abou-el-Seoud, M.O. (1966) *Econ. Bot.* 20, 251.

74. Gregory, K.R. and Reade, A.E. (1973) Personal communication to IDRC (Microbiol. Dept. Univ. Guelph, Canada.)

75. Godfrey-Sam-Aggrey, W. (1973) Mimeo*.

76. Guimaraes, M.L. and Cresta de Barros, M.S. (1972) *Bol. Tec. Div. Tecnol. Agr. Aliment. (Brazil)* 4, 4.

77. Gurnah, A.M. (1973) Mimeo*.

78. Hamid, K. and Jalaludin, S. (1972). *Malay. Agric. Res.* 1, 48.

79. Henain, A.E. and Cenoz, H.M. (1969) Bibliography on cassava, Fac. Agron. and Vet., Univ. Nac. Nordeste, Corrientes, Argentina.

80. Hendershott, C.H. *et al.* (1972) Literature Rev. and Res. Recommendations on Cassava. AID Contract csd/2497, Univ. Georgia, Thens, Ga. USA.

81. Hew, V.F. and Hutagalung, R.I. (1972) *Malay. Agric. Res.* 1, 124.

82. Hoffman, A.S. (1973) Mimeo.*

83. Hoseney, R.C., Finney, K.F., Pomeranz, Y. and Shogren, M.D. (1971) *Cer. Chem.* 48, 191.

84. Hrisshi, N. and Jos, J.S. (1973) Mimeo.*

85. Hunt, A. (1973) Personal communication to IDRC (Crop Sci. Dept. Univ. Guelph, Canada).

86. Imam, M.M. (1972) *Ghana, J.Sci.* 12, 19.

87. Indira, P. and Jurian, T. (1973) Mimeo*.

88. Indira, P. and Sinha, S.K. (1970) *Ind. J. Plt. Phys. 13, 24.*

89. Ingram, F.S. (1969) Rep. G51, *Trop. Prod. Inst.*, London.

90. Ingram, J.S. and Humphries, J.R.O. (1972) *Trop. Sci.* 14, 131.

91. International Institute for Tropical Agriculture, (IITA) (1972) Proc. IDRO/IITA Cassava Mosaic Workshop, Dec. 1972, IITA, Ibadan, Nigeria.

92. International Trade Centre, (1968) The markets for manioc as a raw material for compound animal feed, UNCTAD/GATT., Geneva.

93. Jalaludin, S. and Oh, S.Y. (1972) *Malay. Agric. Res.* 1, 77.

94. Juarez, G. (1955) Bull. 58, Est. Exp. Agric. La Molina, Lima, Peru.

95. Kartha, K.K., Gamborg, O.L., Constabel, F. and Shyluk, J.P. (1974). Nat. Res. Counc. Saskatoon, Canada.

96. Ketiku, A.O. and Oyenuga, V.A. (1972) *J. Sci. Fd. Agric.* 23, 1451.

97. Kim, J.C. and de Ruiter, D. (1968) *Food Technol.* 22, 867.

98. Kitajima, E.W. and Costa, A.S. (1976) Mimeo*.

99. Krochmal, A. (1973) Mimeo.*

100. Krochmal, A. and Samuels, G. (1970) *Ceiba* 16, 35.

101. Lagendijk, J. and Pennings, J. (1970) *Cer. Sci. Td.* 15, 354.

102. Lathrap, D.W. (1973) Mimeo.*

103. Leatherdale, D. (1973) Cassava Thesaurus, CIAT, Cali, Colombia.

104. Lee, T.K.C. (1972) Thesis Fac. Agric., Univ. Malaysia.

105. Lee, T.K.C. and Hutagalung, R.I. (1972) *Malay Agric. Res.* 1, 38.

106. Lozano, J.C. and Booth, R.H. (1974) *PANS*, London, 20, 30–54.

107. Magoon, M.L. (1967) Proc. Int. Symp. Trop. Root Crops 1, 100 Univ. W. Indies.

108. — — — — — (1970) Proc. 2nd Int. Symp. Trop. Root Crops 1, 58. Univ. Hawaii.

109. Magoon, M.L., Jos, J.S., Vasudevan, K.N. and Nair, S.G. (1969) *Genetica Iberica* 21, 27.

110. Magoon, M.L. and Krishnan, R. (1973) Mimeo.*

111. Mehendranathan, T. (1971) *Malay. Agric. J.* 48, 77.

112. Maner, J.H. (1972) Mimeo. Seminar on swine production in Latin America, Sept. 1972. CIAT, Cali. Colombia.

113. Maner, J.H. (1973) Mimeo.*

114. Maner, J.H. and Gomez, G. (1973) In 'Nestel and Mac-Intyre' P. 113. (see ref. 113).

115. Martin, F.M. (170) Proc. 2nd Int. Symp. Trop. Root Crops 1, 53. Univ. Hawaii.

116. Mathot, P.J. (1972) Production and export control in Thailand and marketing in Europe of tapioca pellets. Thai Tapioca Traders Assn., Bangkok.

117. Maust, L.E., Pond, W.G. and Scott, M.L. (1972). *J. Anim. Sci.* 35, 953.

118. Miche, C. (1971) Mimeo. Root and tuber crops in W. Africa, Seminar 22–26 Feb. 1971, IITA, Ibadan, Nigeria.

119. Monge, F. (1973) Mimeo.*

120. Mogilner, I., Portuguez, A.J.D., Botuzzo, A.D. and Acosta, J.A. (1967) *Bonplandia* 2, 137.

121. Montaldo, A. (1967) Bibliografia de Raices y Tuberculos Trop., Univ. Cetn. de Venezuela, Maracay.

122. — — — — — (1973) *Trop. Sci.* 15, 39.

123. Mors, W.B. (1972) *Bol. Tec. Cent. Tecnol. Agr. Aliment. Rio de Janeiro.* 1, 12.

124. Mosha, A.C. (1972) Mimeo. Mandioca Fort. Conf. 13–15 March 1972, Rio de Janeiro.

125. Mota, T.P. (1970) *Agron. Mocamb.* 4, 21.

126. Müller, Z., Chou, K.C., Nah, K.C. and Tan, T.K. (1972) Mimeo. Rep. NUT. (Pigs) R672, FAO, Singapore.

128. Nagarlajan, V., Bhat, R.V. and Tupule, P.G. (1973) *Environ. Phys. Biochem.*, 3, 13.

129. Narasimhan, V. and Arjunan, G. (1973) Mimeo.*

130. Nartey, F. (1973) In 'Nestel and MacIntyre' p. 73. (see ref. 133).

131. Natarajan, R. and Rengasamy, P. (1973) Mimeo.*

132. Natarajan, R. and Vijayakumar, G. (1973) Mimeo.*

133. Nestel, B.L. and MacIntyre, R. (Eds.) (1973) *Chronic Cassava Toxicity.* Proc. Interdisciplinary Workshop, IDRC, Ottawa.

134. Nicol, B.M. (1952) *Brit. J. Nut.* 6, 1.

135. Normanha, E.S. (1970) Proc. 2nd Int. Symp. Trop Root Crops 1, 61. Univ. Hawaii.

136. Nyiira, Z.N. (1973) Mimeo. Rep. on studies on Min. of Ag., Kampala, Uganda.

137. Obigbesan, G.O. and Agboola, A.A. (1973) Mimeo.*

138. Oke, O.L. (1973) In "Nestel and MacIntyre' p. 97. (see ref. 133)

139. Okigbo, B.N. (1973) Mimeo.*

140. Onochie, B.E. and Makajuola, G.A. and Schulte, E.E. Mimeo.*

141. Osuntokin, B.O. (1973) In 'Nestel and MacIntyre' p. 127. (see ref. 133)

142. Oyenuga, V.A. and Opeke, L.K. (1957) *W. Afr. J. Biol. Chem.* 1, 3.

143. Park, Y.K. and Lima, D.C. (1973) *J. Food Sci.* 33, 356.

144. Peterson, J.L. (1973) Personal communication to IDRC. (Dept. Plant Path. McGill Univ. Canada).

145. Perten, H. (1970) Composite Flour Program, Doc. Package No. 1, FAO, Rome.

146. Phillips, T.P. (1973) Cassava, a study of its utilization and potential markets. IDRC Ottawa.

147. Pringle, W., Williams, A. and Hulse, J.H. (1969) *Cer. Sc. Td.* 14, 114.

148. Raeburn, J.R., Kerkham, R.K. and Higgs, J.W.Y. (1950) Rep. on a survey on problems of mechanization of native agriculture in tropical African colonies, H.M.S.O. London.

149. Rankine, L.B. and Houng, M.H. (1971) Dep. Agric. Econ. Occ. Series 6 Univ. W. Indies, Trinidad.

150. Rasper, V. (1969a) *J. Sci. Fd. Agric.* 20, 165.

151. ------ (1969b) *J. Sci. Fd. Agric.* 20, 642.

152. Rapwer, V. (1971) *J. Sci. Fd. Agric.* 22, 572.

153. Rasper, V., Mak, H.M. and de Man, J.M. (1972) Mimeo. Prodn. and Mkting of composite flours meeting, 23–27 Oct. 1972, Bogota, Colombia.

154. Renvoize, B.S. (1972) *Econ. Bot.* 26, 352.

155. Roa, G. (1973) Personal communication (CIAT, Colombia).

156. Rogers, D.J. (1959) *Econ. Bot.* 13, 261.

158. Rosenthal, F.R.T., Barbosa, C.M., Mello, A.P. and Silva, S.M.O. (1972) *An. Acad. Bras. Cienc.* 44, 55.

159. Ross, E. and Enriquez, F.Q. (1969) *Poult. Sci.* 47, 846.

160. Rosseto, C.J., Veiga Leao, A.F.S., Pereira, A.S. and Normanha, A (1973) Mimeo.*

161. Sadi, S. (1973) Mimeo.*

162. Schmidt, N.C. and Pereira, A.S. (1968) *Bragantia* 27, 249.

163. Serck-Hansen. (1970) *Arch. Environ. Health* 20, 729.

164. Serres, H. (1969) *Rev. Elev. Vet. Pays. Trop.* 22, 529.

165. Serres, H. and Tillon, J.P. (1972) *Rev. Elev. Vet. Pays. Trop.* 25, 455.

166. Shank, R.C., Wogan, G.N., Gibson, J.B. and Nondasuta, A. (1972) *Fd. Cosmet. Toxicol.* 10, 61.

167. Shultz, T.A., Chicco, C.F., Sjultz, E. and Carnevali, A.A. (1970) *Agron. Trop. (Macaracay)* 20, 185.

168. Shultz, E., Shultz, T.A. and Chicco, C.F. (1970) *Agron. Trop. (Macaracay)* 20, 421.

169. Shultz, T.A., Shultz, E. and Chicco, C.F. (1972) *J. Anim. Sci.* 35, 865.

170. Sinha, S.K. and Nair, T.V.R. (1971) *Ind. J. Gen. and Plat. Brdg.* 31, 16.

171. Smith, B.C.G. (1970) *E. Afr. Agric. For. J.* 35, 319.

172. Springer, B. (1972) Personal communication to IDRC (Dept. Biometrics, Univ. W. Indies, Trinidad .)

173. Srivasta, H.C. and Patel, M.M. (1973) *Die Starke* 25, 17.

174. Stanton, W.R. and Wallbridge, A. (1969) *Process Biochem.* 6.

175. Strassner, J., Abbott, J.A. and Battey, R.F. (1970) *Food Eng. (May)* 112.

176. Tan, K. (1973) The Tapioca Indust. in Malaysia. Ph D. Thesis. Univ. Malaysia, Kuala Lumpur. Malaysia.

177. Teixera, C.G. (1950) *Bragantia* 10, 277.

178. Tejada de Hernandez, I. and Bramoila, S. (1969) *Technica Pecuaria en Mexico,* 12–13, 5–11.

179. Teleni, E. (1972) *Fiji Agric. J.* 34, 81.

180. Toury, J. and Giorgi, R. (1966) *Ann. Nut. et Alimentation.* 20, 111.

181. van Schoonhaven, A. (1973) Personal communication. (CIAT, Colombia.)

182. Velikaya, E.I. and Nguen Din Thyong (1971) *Izv. Vyssh. Uchebn. Zaved Pishch. Teknol.* 3, 57.

183. Vijaya, M.R. and Aiyer, R.S. (1969) *Agric. Res. J. Kerala* 7, 84.

184. Wahby, O. and Eriksen, S.G. (1969) Tapioca Ind. in W. Malaysia, Food Technol. and Res. Centre, Serdang Malaysia.

185. Wholey, D.W. and Cock, J.H. (1973) Mimeo.*

186. Williams, C.N. (1971) *Expl. Agric.* 7, 49.

187. Williams, C.N. (1972) *Expl. Agric.* 8, 15.

188. Williams, C.N., Beeny, J. and Webb, B.H. (1969) *Trop. Agric. (Trin).* 46, 47.

189. Williams, C.N. and Ghazali, S.M. (1969) *Expl. Agric.* 5, 183.

190. Yong, C.W. (1970) *Malay. Agric. J.* 47, 483.

TABLE 1

Human intake of cassava in 14 countries 1964—66

(Source: FAO Food Balance Sheets 1974-66)

	Human population (million)	Cassava as % total calories	Calories per day from cassava	Cassava consumed per year (kg/head)
Congo(Brazzaville)	0.84	54.8	1184	470
Zaire	15.63	58.5	1193	437
Central African Rep.	1.33	48.7	1057	354
Gabon	0.46	47.0	1027	342
Mozambique	6.96	42.6	908	304
Angola	5.15	34.5	659	220
Liberia	1.08	26.2	600	201
Togo	1.64	26.5	590	197
Dahomey	2.36	20.1	438	148
Paraguay	2.03	19.7	540	181
Ghana	8.14	18.2	380	130
Brazil	80.77	10.8	274	107
Nigeria	58.48	14.1	306	103
Indonesia	105.74	15.3	269	92
Total:	304.15	-	-	-
Weighted average (14 countries)	-	19.4	374	124