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THE UTILIZATION OF CASSAVA VARIABILITY ON AN
INTERNATIONAL BASIS

The Report of a Study Group* compiled by

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INTRODUCTION

The importance of cassava as one of the world's most efficient producers of edible carbohydrate is being increasingly recognized in many parts of the world. With this recognition has come an increase in research aimed at improving the crop by breeding. This is therefore an opportune time to take stock of the potential offered by the available germplasm, and to consider how it can be best utilized. The subject is also timely in view of the considerable interest being shown in the conservation of genetic resources by the Food and Agriculture Organization of the United Nations, and the International Biological Program,

The need to acquire and maintain collections of germplasm becomes increasingly apparent as the wide range of variation in cassava and its related species is recognized. This range must be preserved in full for future generations of breeders, whose requirements might well differ from ours. But germplasm collections are notoriously expensive to maintain and it is essential to organize them efficiently. Moreover, two problems must be solved before efficient, world-wide exchange

*Acknowledgement: The contributions of M. de Albuquerque, E.V. Doku, B.A.C. Enyi, W.O. Jones, A. Montaldo and D.J. Rogers are gratefully acknowledged.

of germplasm can occur: one is the problem of avoiding the introduction of viruses and other diseases to countries where they do not occur, and the other is the problem of standardizing evaluatory procedures and assembling information on germplasm in such a way that breeders have ready access to it, and are able to choose the most useful material for their purpose.

For these reasons, the International Society for Tropical Root Crops set up a study group to draw up recommendations for the utilization of cassava variability on an international basis, and to present them at the present symposium. It was realized, of course, that first priority must go to actual breeding work in progress or being started, and we do not suggest any diversion from his work or diminution of its impetus. Rather, we wish to ensure that full impetus is maintained, because as breeding progresses it will become increasingly desirable to consider how to organize the germplasm so that its full potential becomes available to the breeders. It is to this question that our recommendations are directed, and, as a preliminary to this we first attempt to define the short and long term goals of cassava breeding.

Goals in cassava breeding

Local problems. The immediate objectives of cassava breeding are always to solve problems that limit production or utilization, but since these differ in different parts of the world the breeding goals vary too. Furthermore, because cassava is used for different purposes in different regions, the breeding goals frequently reflect the different priorities given to cassavas for home consumption, for fresh and processed foods, for industrial starches, and so on. Hence, it is often desirable for breeders to consult with economists and even with

politicians before determining their breeding priorities.

Each area also has particular diseases and pests which limit production, and these may change as new diseases arise or as old diseases are transmitted to new areas. It is important to identify these and to identify sources of resistance to them. Resistance to mosaic disease is essential for most parts of Africa. It is said to be moderately severe but still serious in inland areas, while its severity makes it an overriding factor in many coastal regions. More careful selection of planting material may be achieved with large-scale management, but this is unlikely to solve the problem. The available resistant cultivars are not immune but highly field resistant, apparently through an ability to restrict virus multiplication and to localize virus. The goal should be to breed cassavas with a level of resistance adequate for the areas where they are to be grown. Further species should be tested for forms of resistance which are easier to select, such as immunity or vector resistance. Resistance to the vector (Bemisia tabaci) has the attraction that it may confer protection against other virus diseases, possibly including undescribed ones.

Resistance to brown streak disease is important only in East Africa. Although the disease reduces yield and renders the roots inedible, new cultivars possess adequate resistance. The goal should be to maintain this while introducing further improvements. The virus diseases important in South America also differ from those important elsewhere, but, in general, virus diseases are probably less important than bacterial diseases in this continent. Sources of resistance to these are known too and the problem is therefore one for plant breeders.

Scale insects, red spider mites and thrips are occasionally important, especially under sub-optimal conditions such as drought, when

they increase rapidly, damage the foliage, and cause the plants to dry out. The reported sources of resistance should be utilized. Drought itself is a major threat in areas of marginal rainfall, and selection for tolerance of these conditions merits high priority in some breeding programs. New sources of drought resistance are needed.

Yield

A major goal is to produce cultivars capable of yielding the maximum number of calories per unit area. Since advances in growing practices are likely to parallel advances through breeding, one objective should be to select cultivars capable of responding to high fertility and improved agronomic practice. But selection must also be done on soils of average or below average fertility, because these too will be used for cassava in the future.

High-intensity cultivation requires a plant architecture that permits close spacing and efficient use of light. The following characteristics for the ideal plant have been suggested: (a) only one shoot arising from its cutting, (b) a high ratio of root to stem, (c) a leaf area index of about 3.5, (d) about 8 tubers, (e) large tubers, (f) early maturity and high bulking rate, (g) leaves placed at a small angle to the stems so that they are held vertically rather than horizontally, and permit greater penetration of light to the lower leaves, (h) narrow leaf laminas, also to permit light penetration, and (i) disease resistance. Another view is that mechanical harvesting will almost certainly require short, compact roots, and that there should be an adequate number of them to compensate for reductions in their size. Tuberous roots form within the first 6 months of growth and all subsequent yield increases are due to their increase in size.

Hence restriction of root size for mechanized management will place a ceiling on yield if there is not an adequate number of roots.

Yield is not merely weight at harvest. The starch content of roots, for example, varies significantly among cultivars, and is a factor affecting absolute yield. Rough skins and irregular shapes reduce the portion of useful yield, while easy-to-peel outer skins give minimal root loss. Extremely large roots are difficult to market, and thus are set aside for less remunerative purposes. Various changes in the root which lead to necrosis, darkening or liquefaction of the starch can be attributed to low tolerance of sub-optimal soil conditions - soils with impeded drainage, for example. These problems are aggravated by fungal pathogens, but sources of resistance to the pathogens are known and should be given special attention when breeding for regions where peasant smallholders 'store' their roots for long periods in the ground.

Yield is also related to time to maturity. Root yield during the second season is usually achieved more efficiently than in the first, and thus for starch and industrial purposes a requirement is for cultivars capable of giving high yields in about 20 months. For these situations, the concept of yield per hectare per month may be more valuable than simple yield measurement, but for other situations the requirement is for cultivars which give an economic return in 6 to 10 months, as these fit better into agricultural rotations and local needs.

In summary, breeding for high yield necessitates studies of the components of yield, but the relative importance of factors which affect yield varies in different regions and thus breeding goals must vary too.

Labour saving

The need to produce more food with fewer hands requires the production of staples which utilize mechanical devices for many steps in their production. In some cases the development of such devices must await the breeding of suitable cultivars, but breeding for characters which facilitate mechanical planting and harvesting would probably yield cultivars suitable for more simple agricultural systems as well. Cassava cultivation on peasants' small-holdings will certainly continue to be of major importance for the foreseeable future. Breeders must always keep the needs of these persons in mind, although selection for the special characteristics required for mechanized systems is not likely to produce cultivars unsuitable for growing on small holdings,

Almost all present-day cultivars produce a few large cylindrical tubers which grow deeply into the soil. This makes both hand and mechanical harvest difficult. The need is for cultivars with larger numbers of smaller and more nearly spherical tubers which do not penetrate so deeply. It is uncertain whether the ideal plant habit is one with erect stems and minimal branching, or one where the stems are of medium height and moderate branching. The former produce material ideal for mechanized planting, but they lodge more easily and are less effective for shading out weeds; while the more profusely branched ones have disadvantages for the application of crop-protection chemicals and for harvesting.

Quality

Except where cassava is used exclusively for industrial purposes, the lowest possible hydrocyanic acid (HCN) content is the most important quality to be sought. Even where HCN is at present dealt with by

well known procedures it is probable that it is not completely removed, and that cumulative ill-effects on health occur due to its regular intake at low levels.

Cassava owes its claim for advancement to its capacity for producing very high yields of calories, and it is said that its roots are organs for starch storage and not adapted physiologically for protein storage. Clearly, improvement in protein content is acceptable only if it is achieved without diminution of this primary function. Nevertheless, the existence of cultivars with higher than average protein content and of related species with high protein content justifies further studies of the feasibility of combining high calorie yield with improved protein content. In these respects our knowledge of the potential of the available germplasm is still limited.

Good cooking quality (floury texture), high contents of sugar, vitamins and minerals, and suitability for processing into numerous local foods are additional qualities required. Processed foods such as tapioca require large starch grains. Developments in the use of cassava flour for bread might introduce other requirements. The industrial usage of cassava will increase both in quantity and in variety. This, too, may lead to variation in the kind of starch required, possibly in grain size or in characteristics such as amylose content. Large grains are required for most purposes but differences in requirements may call for specialized cultivars.

The need for new germplasm

Cassava improvement requires new germplasm for two main reasons: to introduce specific characters and to broaden the genetic base. Specific characters such as disease resistance or quality attributes

are usually transferred to locally adapted types by repeated backcrossing. However, it is often difficult to recognize the usefulness of a new specific trait in a 'wild' background, even though it could be revolutionary and give a major breakthrough if incorporated into an adapted cultivar. This difficulty can only be met by careful study of germplasm collections by people representing a wide range of interests and competence.

Where the transfer of a specific character from a related species by backcrossing has been attempted, benefits have frequently occurred over and above those predicted from the specific improvement alone. This is because 'fringe' benefits occurred from general improvements associated with broadening the genetic base. Prolonged backcrossing is not as effective for taking advantage of these as a system which allows intercrossing after the first or second backcross. The objective should be to recover most of the adapted parents' germplasm plus all the useful new germplasm. Large segregating populations will be required, especially where negative correlations occur between a desirable character and an objectionable one.

The wide morphological variation among cassava cultivars suggests that cassava had a polyphyletic origin and hence has a fairly wide genetic base already. Nevertheless, further broadening of the genetic base may possibly be achieved dramatically by 'starting again', that is to say, by selecting over several generations among wild species of Manihot for forms productive of good roots. The selections obtained might then be used to produce productive hybrids with cassava cultivars. This idea is stimulated by success recently reported for a similar project with potatoes, where material of Solanum andigenum has been successfully selected with greatly improved tuber yield and then crossed

with potato cultivars to give hybrids with 50% more yield than typical S. tuberosum progenies. Obvious candidates for improvement prior to crossing with cassava are species with tuberous roots and low HCN content. Another objective is to widen the area where cassava can be grown successfully, for which task the introduction of germplasm from other Manihot species is particularly desirable, as the ecological range that they cover is considerable.

The acquisition of germplasm

A start has been made in the development of germplasm collections, but these are not yet extensive. Four categories of germplasm should be preserved: elite cultivars, breeding material carrying genes for special characteristics, ordinary cultivars, and wild species. The four categories are not of equal importance and merit different consideration. The most important are cultivars or hybrids which are elite because they have given outstanding performance in trials, have proved themselves outstanding parents or contain rare combinations of genes such as genes transferred by interspecific crossing. Comprehensive collection of the other categories is of lower priority, and is a long-term task which should be done as an organized operation sponsored by an international body. Collections should be made on an adequate scale and with adequate objectives, and isolated expeditions with specialized objectives should be replaced by systematic collecting aimed at including as many ecological variants as possible of each species, especially those closely related to M. esculenta. This implies a major study based on knowledge in depth and a thorough ecological appreciation of the areas explored. The preparatory work will require just as much time and labour as any major investigation.

The maintenance of germplasm (a) Manihot species

It is desirable to maintain the germplasm in germplasm centres, whose responsibility should be to locate and acquire it, and then to maintain and rejuvenate it as necessary. Only seed maintenance need be considered for wild species, which do not propagate easily from cuttings. Research is required to determine the optimum storage conditions for Manihot seeds in terms of moisture content, temperature and gaseous content of the storage atmosphere. In other genera, reduction in water content and attention to these other factors has permitted seed storage for 20 years, but this has not always been achieved for species whose seed has a high oil content. Success with Manihot would enable germplasm to be maintained entirely as seed, only a small proportion being grown for rejuvenation at one time. The maintenance of a living collection would not be a primary requirement, as material required for particular projects would be grown especially in the most appropriate areas. For example, studies concerned with pathology or with adaptation to an environment must necessarily be done in areas where the particular disease or particular problem of adaptation occurs. Where individual breeders prefer to maintain their own collections the material would also be received from a germplasm centre. None of these purposes would require the complete collection, and material grown for short to medium term projects could later be discarded, because the centres would provide continuity.

The maintenance of germplasm (b) Cultivars

A very large number of cassava cultivars exist in most tropical countries. They often represented variants evolved from a relatively narrow base of germplasm and perpetuated by clonal propagation. A

serious erosion of germplasm could occur when existing cultivars recede in the face of superior ones produced by breeding, and efforts should be made to prevent such losses. Analyses of the variation would probably show groupings which reflect the origins of the cultivars, and it may simplify the situation if such groups were regarded as populations. Their basic germplasm could probably be adequately maintained in the form of seed, as the cultivars are really no more than the elite individuals of a population. Again, a big advantage of this would be achieved if long-term storage of the seed became possible, as only a fraction of the material would then be grown at one time. The facilities of a central seed bank would be used, and all the disadvantages of collections maintained by cuttings avoided. Collections of cuttings are more difficult to acquire for reasons concerned with plant health. They can be based on fewer plants than collections maintained by seed, but the total collection must always be maintained as living plants. Experiments with storage of cuttings may show how the work could be reduced slightly.

Problems arise in ensuring the maintenance of germplasm in seed mixtures: different genotypes within a seed sample may have different abilities to survive, especially when the germination capacity of a sample is reduced by long storage; there may be differential survival or capacity to reproduce during the rejuvenation phase, possibly due to differences in inflorescence production or in capacity to set seed; outcrossing with other populations might occur if isolation is insufficient, while practicalities may dictate small sizes of population, and lead to "genetic drift", *i.e.*, fixation of particular alleles at the expense of others, which will be lost. Fixation of deleterious genes often occurs in small populations, as it occurs independently

of adaptive value.

Some of these problems are aggravated because the capacity of cassava to reproduce by seed is so variable. Indeed, the variation is so wide that it precludes the use of large panmixia of material, because they would become dominated by the more fertile kinds. Possibly a fairly large number of groups should be started and then combined progressively as evidence of similarity is obtained. Use of a small number of large groups would be easier and would also minimize genetic drift, since in a large population few if any genes tend to be eliminated.

The maintenance of germplasm (c) Elite breeding material

In the case of very select cultivars and hybrids the individual clones are outstanding for their particular combination of genes, and they are usually so heterozygous that only a small proportion of their seedling progeny adequately represent them. Breeders therefore prefer to breed from the cultivar itself, which therefore has to be maintained clonally. Outstanding breeding stocks and sources of disease resistance fall into this category.

For these materials, expensive measures to satisfy quarantine requirements are justified in order to make elite material from all regions available to all breeders. Thus, material which had been exposed to virus infection could first be grown in quarantine, and then possibly cured by heat therapy or by propagation from apical meristems. Where the risks are high, quarantine should be enforced in the country of origin and repeated in the importing country. No effort should be spared to keep the collections virus-free, so that recipient countries can accept material with minimal delays and

restrictions.

The evaluation of germplasm

Material in the germplasm centres must be rigorously tested, and its attributes and characteristics documented in detail if it is to be used effectively to attain the breeding goals defined. This will entail testing under a range of conditions to evaluate genotype-environment interactions for important plant characters. Indeed, testing at several centres will be necessary to obtain all the requisite facilities for testing the many qualities being sought. The aim should be to identify material not only by its number and place of origin, but also by its test ratings for as many characteristics as possible. Information on such characters as resistance to diseases, quality of roots and their suitability for various purposes, growth pattern in terms of characters likely to affect yield and adaptation to particular environments should accumulate, and be added to a store of information. Computerized procedures for processing this data should then be used. Such a record in a central file with facility for rapid retrieval of information would greatly facilitate the use of germplasm collections by providing speedy information about new accessions and discoveries of special characters. The record system would allow for revision and alteration as information accumulates, as this would happen as studies of a general nature were followed by an increasing number of studies by specialists. The specialists involved may not all be primarily concerned with plant breeding, as basic studies in such disciplines as taxonomy, cytogenetics and pathology are also facilitated by germplasm collections.

The standardization of testing and evaluatory procedures

The high cost of experimental work means that ~~experiments~~ must be planned to give a maximum of information that is useful in any geographical area to which it is relevant. Good experiments accurately reported make unnecessary the continuous repetition of similar experiments in distinct regions. But only if investigators all over the world use similar reporting techniques will they be able to use each other's results.

The general problem of experimental design has been handled admirably in "A Guide for Cassava Field Trials" printed by the Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. The information given is too extensive to include here, but should be consulted by persons interested in the agronomy of cassava. Of particular value are a series of standard forms for planning experiments, recording background information, maintaining a diary of experimental procedures, recording economic data, information on climate and plant diseases and preserving samples. Such information makes it possible to compare the details of experimental results from diverse regions. Permission is given in the manual to reproduce and use these forms. In this report, standard procedures are considered only for the purpose of cultivar testing, and the measurement of yield under a given set of conditions is emphasized.

Trials are managed at several levels, only some of which allow the possibility of international cooperation, but it is highly desirable that tests involving exchanges of materials be standardized. Selection frequently occurs in the following stages, and will usually be for many factors besides yield:

1. Preliminary screening among seedlings or new accessions, based

on single plants.

2. Unreplicated comparisons of ~~short runs of preliminary selections~~ to reduce the selections to a workable number.
3. Replicated trials to select a small number of genotypes for trial under well-defined conditions.
4. Final trials in replicated large blocks at several locations.

Duplication for assessments of genotype x environment interactions in respect of planting time, high and low fertility, or high and low rainfall should be introduced at stage 3 or 4, to indicate a genotype's 'stability' or 'responsiveness'.

Much of the material moved internationally will be of sufficient merit to be tested directly in replicated trials, once sufficient material is available. New rapid propagation methods must be perfected to facilitate this. Some recommendations for standardized experiments are:

1. Randomized block design. Alternatively, a balanced lattice, especially where computerized analyses are possible.
2. Four to six replications.
3. Where material is abundant, each plot should be rectangular in shape, and be surrounded by two border rows of the same variety and treatment combination.
4. Uniform planting material, spacing, fertilizer, insecticidal, fungicidal and other treatments, providing that the standardized procedure does not conflict with the local practices under which the selected cultivars will be grown.

Although recording can be managed most effectively on the forms in the CIAT manual, it is unlikely that these will always be used, because they are very extensive. A shortened form has therefore been

devised (see attachment). ~~Many important~~ items are clearly omitted from it, but other information can always be added. It is appropriate to consider here some standardized methods of measuring certain other variables:

Dry matter content. Dry matter determinations of sufficient accuracy for most purposes can be made by drying cassava chips to a constant weight in an oven at 55-60°C and expressing this weight as a percentage of the fresh weight.

Starch content (Mechanical method). Duplicate 50 gm samples of fresh roots are placed in a blender containing 500 ml of water and macerated for 5 minutes. The starch is then washed out of the pulp through a 200-mesh screen with 500 ml of water, dried in a suitable pan in a forced-draft oven at 85°C, and its dry weight determined and expressed as a percentage of its fresh weight.

Starch content (Root density method). The starch content of a sample of roots can be estimated from its specific density. The latter is determined by dividing its weight in air by the difference between its weight in air and its weight in water. Fairly large samples of 5-10 kg should be used. The CIAT manual gives a table to convert specific densities into starch contents, but it may be desirable to verify these conversions locally.

HCN content. Guiguard's test is suitable for rapid primary screening. For this test, sodium picrate paper is first prepared as follows: prepared filter paper is dipped into 1% picric acid, dried, dipped

into 10% sodium carbonate and dried again. For the test, a few grams of finely chopped root are placed in a test-tube, a few drops of chloroform added, a moist strip of the sodium picrate paper inserted and the tube tightly stoppered. After 3 or 4 hours the amount of free HCN released will be indicated by the intensity of red coloration on the paper, which can be scored on a 0-5 scale. A more exact quantitative method should then be used for selections giving low scores. The method described by Wood (J.Sci.Fd.Agric., 1965, 16,300) seems suitable.

HCN content is influenced by many variable which should always be noted: plant age and soil fertility, for example. Account must also be taken of variation within a plant. All of its roots should be peeled and cut into transverse sections to take account of variation between roots, and these sections should be sampled with a cork borer to take account of variation within them.

Disease resistance. For assessment of disease resistance it is important to choose a locality and management system which maximises the discrimination between genotypes. Preliminary experiments to determine the best system are often needed and details of factors such as climate, time of planting and soil fertility should always be reported. For maximum discrimination, records of the proportion of plants infected, the proportion of branches infected (since for many diseases branches are infected independently) and the intensity of symptoms are often desirable, particularly when computerized techniques can be used to combine them into a single figure which is more discriminating than any one of them alone.

Facilitating international exchange of materials

Two factors facilitate international exchange more than any others. The first is the provision of adequate information for recipients to know exactly what is available so that they receive precisely what they require, and the second is the establishment of procedures which permit germplasm exchange with minimal delay and with minimal risk of spreading diseases or pests.

We have described how information should be accumulated and incorporated into a computer system at the germplasm centres. In an ideal situation a breeder applies for material of a particular type which fulfils particular requirements. The computer then lists the materials available which meet the stated requirements, and the breeder selects from the list: success depends on the completeness of the information available and on the extent to which its form is meaningful to all readers.

Quarantine controls must be rigorous, but the delays caused by them can be minimized by choosing ways of exchanging materials which have minimal risks of spreading disease. Certain centres, possibly the germplasm centres, should maintain a nucleus of material at such a high health standard that foreign countries will accept it with minimal restriction. But more study should be given to the possibility of exchange of seeds or pollen, for which risks of spreading disease are less. There are many possibilities: 1) A breeder may exchange open-pollinated seed. This may be satisfactory for supplying germplasm for a particular character whose inheritance is not complex, but it is not a good way of distributing an elite genotype. 2) A breeder may repeat a cross which has produced a progeny containing elite individuals, and distribute the seed. Since it is often

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particular combinations which give overall superiority, this method gives other breeders the opportunity to test superior combinations and to select for local adaptation as well. 3) A breeder may make a cross between a superior parent and parents known to be adapted to a recipient country. This is useful where the contribution of the superior parent is inherited in a simple or additive way, and could be used in a back-crossing program following interspecific hybridization. For such a program, one centre may proceed as far as the first or second backcrosses, and then distribute second or third backcross seed, the seed for each situation being obtained by crossing with parents chosen for that particular situation. 4) A breeder may attempt to produce improved populations by recurrent selection, and distribute seed to be tested for local adaptation after successive cycles of selection.

Modifications are possible if pollen exchange is considered.

Prolonged pollen storage is possible in other genera and studies are needed to determine the optimum conditions for storage of cassava pollen. If successful, this method would allow a donor center to store pollen of superior parents for long periods pending requests for its use. Small quantities could then be sent to recipients at the most opportune time for crossing.

These methods have other advantages over the exchange of cuttings. They remove the delay caused by quarantine and the time required for establishment and flowering of the imported clone prior to its use in making crosses.

CONCLUSIONS

We conclude that there are considerable benefits to be gained

from organizing cassava variability on an international basis. Broad breeding goals, including the acquisition of materials and the screening for certain basic traits, can best be handled at large international centres, while local needs must be handled locally, though individual breeders should make increasing use of germplasm supplied by the larger centres. We propose a system of international germplasm centres, possibly one each for Africa, the Americas and Asia. These should not only facilitate the acquisition and maintenance of what is potentially a vast reservoir of germplasm, but should also fulfill the functions of collecting and distributing the information gained from it. We realize that the creation of such centres are long-term projects, but in the meantime, some of their objectives can be achieved by collaboration between breeders in a less organized way. Indeed, closer informal contacts between breeders is needed whatever formal organizations are eventually set up, because some of the procedures advocated here call for a degree of cooperation not as yet achieved. Developments at the International Research Centres already call for greater cooperation, particularly between breeders at these centres and breeders in individual countries. We therefore advocate the creation of a Cassava Breeders' Association, preferably within the International Society for Tropical Root Crops, whose role should be to promote informal contacts and exchanges of information, especially on germplasm and on techniques, and to facilitate the planning of collaborative projects in the field of cassava breeding.

CASSAVA VARIETY TEST RESULTS

(SHORT FORM)

Name and address of investigator _____

Area where varietal trial held _____

General characteristics of climate _____

General characteristics of soil _____

Factors which limited the test _____

Propagating material _____

Planting method and spacing _____

Fertilizers and soil amendments _____

Insect and fungicidal control measures _____

<u>Varieties</u>	<u>Fresh weight marketable yields per hectare</u>	<u>Dry weight yields on conversion</u>	<u>Significance of differences</u>
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Interpretations (recorded on reverse side):

Noteworthy characteristics or limitations of varieties (recorded on
other side):

CASSAVA BREEDING AT I.I.T.A.

by
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ABSTRACT

The importance of cassava as a staple food crop in Africa was stated and major problems involved in production in the area were briefly discussed. The cassava breeding objectives in the Root and Tuber Improvement Program of the International Institute of Tropical Agriculture (IITA) were laid down. Basic considerations in cassava breeding were reviewed and discussed. The paper attempted to produce a cassava breeding system applicable on a world-wide basis and to describe the present state and the future development of cassava breeding.

Résumé

L'auteur fait état de l'importance du manioc en tant que culture vivrière principale en Afrique et des problèmes relatifs à sa production dans cette zone. Les objectifs de l'amélioration du manioc dans le cadre du programme de l'amélioration des plantes à racines et à tubercules de L'Institut International d'Agriculture Tropicale (IITA) sont formulés. Des considérations de base de l'amélioration du manioc sont examinées. La communication a tenté de mettre au point un système d'amélioration du manioc ayant une application universelle et de décrire l'état actuel et les perspectives pour le développement de l'amélioration du manioc.

INTRODUCTION

Cassava is widely grown and used as a preferred staple food in many parts of the tropics. World production amounts to about 100 million tons annually from 10 million hectares, of which Africa produces about 40 million tons from about 5 million hectares. In Africa, especially West Africa, cassava is the most popular of the root and tuber crops and the trend in production shows a steady increase (FAO Yearbook, 1971).

Cassava is potentially able to produce more food calories per unit area than any other lowland crop, owing to its high yielding ability, adaptation to diverse climatic and cultural conditions and ability to survive the four to six month's dry season. It requires less management input than cereal crops. Both root and leaf are valuable as human food and livestock feed, the leaf protein is high in quantity and of good quality in some varieties and the root is widely used for industrial production of starch and alcohol. It is believed that these factors will encourage the expansion of cassava growing in both the humid and sub-humid tropics.

I.I.T.A. initiated its Root and Tuber Improvement Program in 1971 and it includes cassava, sweet potato, yam and cocoyam, all of which are important food crops in many parts of Africa. However, in view of cassava's potential and its economic importance within the lowland humid tropics, priority is given to this crop. The main aims are to improve yield both in quantity and quality and to breed for resistance to the major diseases; bacterial wilt

and cassava mosaic. At present the average yield of cassava in Africa is very low being about 9 tons per hectare per year fresh weight, equivalent to 3 tons dry weight. The optimum criteria for quality are not well defined or known, but definite improvements can be made in advance of this knowledge. Cassava mosaic is a serious problem in Africa, as it is in India and Indonesia. Nearly all plants are infected resulting in an average yield reduction of 50 per cent (Jennings, 1970). Bacterial wilt (Xanthomonas manihotis) has recently been reported in Africa. In Nigeria (Williams, et al. 1972) and in Zaire (Williams and Hahn, 1973) reported that it causes severe tip die-back and leaf defoliation, often resulting in the death of the plant. It is now thought that bacterial wilt is potentially a more serious disease than cassava mosaic within the areas affected.

The cassava improvement program at I.I.T.A. involves the disciplines of Agronomy, Breeding, Entomology, Plant Pathology (Virology), Plant Physiology and Biochemistry, and in addition receives support from Agricultural Economics and Agricultural Engineering. Their combined efforts are being directed towards identifying and solving the problems involved in cassava production in the lowland and humid tropics of Africa.

Though cassava is economically important in many other parts of the world, breeding for improvement in this crop has been given very little attention compared with other crops. There is practically no information on the practical and

fundamental approaches in breeding for the solution of many of the problems limiting or inhibiting the use of cassava. The breeding work initiated in 1930 to 1950 in East Africa, West Africa, Brazil, Indonesia and Madagascar appears for the most part to have been abandoned.

Our aim is to produce a breeding system applicable on a world-wide basis and this paper describes the present state and future development of I.I.T.A.'s program. It evaluates the possibility of incorporating some of the methods already successfully used in breeding corn, alfalfa, sorghum and sweet potato.

BREEDING OBJECTIVES

The ultimate goal of cassava breeding is to incorporate and stabilise into our varieties all the characteristics not yet fully explored, which are associated with high yield, both in terms of quantity and quality per unit of area and time, within a wide range of environments and cultural practices.

Ramos (1970) reported from S. America that the variety Llanera produced 78 tons of tuberous root per hectare from experimental plots and Magoon (1970) stated that tuberous root yields from Indian breeding clones produced by inter-varietal hybridization yielded from 23.5 to 84.7 tons per hectare as compared with 10 to 31 tons from the control plot. Abraham (1957) reported yield as having a fairly high heritability. These facts indicate that a two to threefold increase is possible. In Nigeria where yields are very poor a great improvement can be

forecast. On a fresh weight basis, our trials of 10 local cultivars produced only 15 to 30 tons per hectare per annum, with a dry weight range of 4 to 10 tons.

Cassava varieties in India can be harvested in 7 to 12 months (Magoon, 1970) and some Colombian varieties in about 10 months (Ramos, 1970). There are many unpublished reports from Africa that some cultivars produce a relatively good yield in 8 to 10 months, compared with the more usual time of one to two years, but very little information is available on optimum time of harvest in respect of dry matter yield or of its economic importance. However, since there is a distinct variability in time to maturity among the existing local cultivars, it will be possible to incorporate an early maturity factor into our program.

It is known that cassava mosaic is one of the most important diseases in Africa, India and Indonesia. In Africa it is very destructive, and adequate control of the disease is very difficult as the causal agent is unknown and to attempt to eradicate the whitefly vector (Bemisia tabaci) is considered to be impracticable. Normal vegetative methods of propagation, inevitably using diseased setts, ensure the continued presence of the disease. Therefore, in the past, priority had been given to breeding for resistance to this disease and a program was first initiated by Storey and Nichols in East Africa in the 1940's, using the wild related species M. glaziovii as their source of resistance. In the 1950's this work was extended in East Africa by Jennings, in West Africa by Beck (1971) and in 1970 in India by Abraham and Magoon. The starting point of the breeding program at I.I.T.A. is the highly resistant clonal material

produced by Beck which was produced by hybridizing his own interspecific hybrids with those of Storey and Nichols. Beck's material has exhibited resistance to cassava mosaic for about 15 years although the vector population in the field is always heavy; unlike the Storey and Nichols hybrids, the resistance of which has not been maintained (Bock, 1973). The yield of these resistant clones is poor in both quantity and quality and the next stage in our program will be to incorporate this resistance into high yielding varieties. There is no doubt that high priority should still be given to resistance to cassava mosaic in view of its severity throughout the world. However, it appears that in previous breeding work in Africa resistance to the disease was overemphasised in the belief that incorporation of resistance would inevitably result in improvement in yield, and little attention was paid to the whole gene complex associated with yield. At I.I.T.A. the criteria currently employed in screening for resistance to cassava mosaic are based mainly on foliar symptom expression; viz: mild chlorosis, severe chlorosis, distortion and size reduction of leaf lamina.

Bacterial wilt (Xanthomonas manihotis Burkholder) was first reported in Brazil in 1915 (cf. C.I.A.T. Cassava Tech. Bull., No. 1, 1973) but it was only recognised in Nigeria in 1972 (Williams et al.) and in Zaire in 1973 (Williams and Hahn). It is now considered to be a more serious menace to the crop than cassava mosaic. It is widespread in these two countries and is the cause of a severe defoliation and tip die-back.

In 1973 screening for field resistance to bacterial wilt was attempted after stem inoculation of about 10,000 clones produced from seed of Nigerian cultivars, I.I.T.A. hybrids and new introductions from Latin America and Asia. The criteria currently employed for screening are based on the following: leaf wilt and petiole exudation, defoliation, tip die-back and stunting. From this it was seen that clones from some of the local cultivars and many of the hybrids were resistant, but all the introductions were highly susceptible. From Colombia, Lozano (1973, personal communication) has reported that of several thousand varieties screened within their germplasm collections five were resistant.

Brown streak, a virus disease which occurs only on the East African coast has a variable effect on yield, but it can be quite considerable. Both M. glaziovii and M. melanobasis have been successfully used as sources of resistance to the disease (Jennings, 1970).

Guiran (1965) reported varietal differences in resistance to the nematode, Pratylenchus brachyurus. At I.I.T.A. some of our seedlings were heavily infected by the root knot nematode Meloidogyne incognita and there appeared to be some differences, at present unexplained, in its incidence within the breeding nursery. Although it caused complete loss of yield in some plants it is not at present regarded as a serious problem at this Institute.

A dry season pest on all local cultivars is the red spider mite (Tetranychus spp.) but a high degree of resistance

seen
to it has been/within the Latin American populations (I.I.T.A. Annual Report, 1972). From India, Magoon (1970), reported a high degree of field resistance in some of his breeding clones, some of which have been imported to Nigeria. Nyiira (1972) has reported a very serious outbreak of Mononychus tanajoa mite infestation in Uganda.

Scale insects (Aonidomytilus albus) heavily infect cassava in Africa during the dry season and are very serious in Zaire, where in some areas over 90 per cent of the crop is infested, causing a bunchy top symptom. Infected plants are stunted and it is likely that considerable yield reduction both of tops and tuberous roots will result (Williams and Hahn, 1973). In India, Magoon (1970) reported clonal differences in resistance to infestation.

A third dry season pest is a grasshopper (Zonocerus sp.) which feeds on the leaves, but there appears to be a varietal preference in this.

There is no evidence of damage from thrips or shoot fly in Nigeria although these are serious pests in Latin America, and may be so in other parts of Africa.

Quality improvement both in terms of higher yield and increase in starch and protein content has so far received little attention, and information on the subject is scarce. The quality of Nigerian cultivars in respect of protein appears to be particularly poor (Oyenuga, 1955) with an average of only 2.5 per cent dry weight protein in the tuber and 14 per cent in the leaf. In comparison, Ramos (1970) from Columbia reported 6.4 per cent

dry weight total nitrogen in the variety Llanera, and over 7 per cent protein in the leaf of other varieties. Rogers and Milner (1963) reported that the leaf of some Jamaican varieties contained 5.4 per cent protein on a fresh weight basis and 25.8 per cent on a dry weight basis, while figures of 7.8 per cent and 27.3 per cent were obtained in some Brazilian varieties. They added that the essential amino-acid profile of cassava leaf indicated a deficiency in methionine only and ^{the} high lysine value recorded was a desirable feature. The relative quantities of the usually limiting amino-acid of leaf protein are fairly satisfactory (Terra, 1964). A large variation in leaf protein content has been found in our germplasm collection, ranging from 18 to 40 per cent dry weight. Further research needs to be done in this field before a program of breeding to increase protein content in the tuberous roots can be undertaken. Although the variety Llanera has a high protein content when grown in Colombia this is not the case when it is grown in Nigeria, probably due to genotype-environment interaction. Higher protein content has been obtained from the hybrids M. esculenta x M. saxicola (Bolhuis, 1953) and M. esculenta x M. melanobasis (Jennings, 1970; Beck, 1971).

Magoon (1970) reported increased starch content in his improved varieties which ranged from 29 to 31 per cent in fresh tuberous roots at 9 months of age, compared with from 20 to 25 per cent in most of his local cultivars. Screening for starch content in our own breeding material revealed considerable variation in both starch and amylose content. The gelatinization

temperature has yet to be checked.

The HCN content of tuberous roots varies with varieties and (Rogers, 1955), with the age of the plant/with environment (Sinha and Nair, 1968; Dulong, 1971). About 90,000 seedlings produced from about 900 cross combinations have been screened for HCN at IITA, using the sodium picrate test and only 0.1 per cent has been found with low HCN, 0.76 per cent medium and the remainder, 99.14 per cent high. None showed complete absence of HCN (Sadik, 1973). It is interesting to note that almost all the seedlings which had a low HCN content were derived from crosses with 58308 (an interspecific hybrid with M. glaziovii), or Isunikankiyan (a sweet cassava). The highest frequency of low HCN content occurred in crosses between these two cultivars.

Cassava is grown in a wide range of environments: in humidities ranging from 500 mm to 5,000 mm annual rainfall, at altitudes from sea level to 1,500 m, latitudes 30°N to 30°S, annual average temperatures from 15°C to 35°C, soils varying from rich loamy to poor sandy and management minimal to relatively intense. As previously mentioned it can survive dry periods of about 6 months or more. However all cultivars would not perform equally well under such a wide range of environments. Cassava has been adapted to specific environments during the process of natural selection and local farmers have obviously selected cultivars suitable to their particular requirements. The cultivars may therefore show differential responses to disease, insect and nematode attack, drought, light intensity, day length, fertiliser response and soil condition. Therefore,

genotype-environment interactions can be expected and, in fact considerable genotype-season interaction effect was recorded in our yield trials and the cassavas from Brazil, Colombia, and India have shown a very poor performance at IITA, which must be due to genotype-environment interaction.

A plant model for both canopy and tuberous roots should also be considered in relation to efficient light interception, utilization of nutrients and accumulation of synthesized carbohydrate in the tuberous root, and for mechanical cultivation, harvesting and processing. Tremendous variation exists amongst cultivars both in canopy, tuberous root characteristics and resistance to lodging.

In this paper we have briefly reviewed and discussed the major problems involved in cassava production in Africa, possibilities for improvement and approaches used to solve these problems in order that the crop may reach its full potential.

Bearing in mind the limiting factors associated with cassava production in Africa we regard the following objectives as realistic and our aim is to produce:

1. High yield in terms of dry matter per unit of land area and time,
2. Multiple resistance to diseases, especially cassava mosaic and bacterial wilt and to insect attack,
3. Improved quality in terms of high starch (both quantity and quality), low or zero HCN and high protein content, especially in the leaf,
4. Wide adaptation to a wide range of environments, and
5. Improved plant types, especially canopy and root characteristics.

BASIC CONSIDERATIONS IN BREEDING

Breeding Materials and Evaluation

The acquisition and selection of superior breeding material is a primary necessity in any breeding program. M. esculenta exhibits a wide variation in form and there are also about 128 other Manihot species (Rogers and Appan, 1970) the genetic variation of which have not yet been fully explored or utilized.

Cassava is indigenous to the new world tropics and was probably first domesticated in the dryer parts of western and southern Mexico, northern Guatemala and northeastern Brazil (Rogers, 1963). It was introduced to the West African coast via the Gulf of Benin and the Congo river at the end of the 16th century; and to Madagascar, Zanzibar, India, Ceylon, Malaya and Indonesia during the 18th century (Jones).

African cassava shows considerable variation. This is not surprising as it flowers and sets seed freely, and new cultivars are established from volunteer seedlings which grow readily under optimum temperatures (30-35°C) and rainfall conditions which occur during some periods of the year. Cassava is rarely self-pollinated, since male and female flowers on the same inflorescence mature at different times. Thus, continuing recombination has occurred from outcrosses of genetically heterozygous cultivars. This can be seen from inspection of the various local germplasm collections in Africa which exhibit many different varieties. Some level of resistance to cassava

mosaic has been established through intelligent selection by local farmers of superior seedlings for vegetative propagation thereby developing new cultivars. Genetic fixation is not required in a vegetatively propagated crop and cultivars can be produced from F_1 hybrids. Somatic mutation may be a cause of genetic variation but it is not as important as recombination resulting from outcrossing, followed by natural seed germination and vegetative propagation.

Genetic variability in Africa is not expected to be as great as in Latin America where cassava originated. Original introductions may be only a section of the germplasm available and it should be realised that the systematic introduction of new breeding material is especially important in areas where the crop is exotic, and although all types of material can be utilised, accessions from areas having similar ecological conditions are the most desirable. Introductions from countries where the crop is indigenous should prove particularly valuable.

Manihot esculenta is the only edible cultivated species (Rogers and ~~Heider~~ Heider ~~et al.~~ et al. 1972). Cultivars within this species have become extremely diversified during the process of evolution and their potential as sources of breeding material is tremendous and unpredictable.

The IITA germplasm collection is far from complete and has not yet been thoroughly evaluated. Quarantine regulations require that introductions of new breeding material be confined to true seed which has had the appropriate fungicide/insecticide dressing, as the risk of introducing new diseases in vegetative

material is high. At IITA the Root and Tuber Improvement Program has adopted this procedure from the beginning and Martin (1970) has predicted that the germplasm banks of the future will be in seed form. Cassava mosaic is not seed borne (Chant, 1958) nor, from our experience, is bacterial wilt. Other pathogens of cassava: Cercospora spp., Botryodiplodia theobromae, Colletotrichum sp. causing stem anthracnose, a Phomopsis sp. causing root rot and Fusarium spp. are endemic in this country and therefore need be of no concern as far as phytosanitary regulations are concerned.

The large number of local cultivars and introductions requires a large evaluation program and general combining ability is most important in preliminary screening. The comparison of all collections as test crosses to a low yielding local variety is often the most satisfactory method of evaluation (Eberhart, et al. 1967). The testcross can be made by growing the germplasm collection and the local test variety in isolation, using the tester as the pollen parent and removing the male flowers from the germplasm collection. The following year evaluation of the testcrosses by growing the seed in replicated trials at several different locations and seasons would give the necessary information and useful agronomic traits should be noted at the same time.

Floral Mechanism and Cross-Pollination

Cassava is monoecious, flowers being separate on the same inflorescence, female flowers at the base opening first and apical male flowers normally opening about a week later. During the

flowering season there is great activity among nectar gathering insects and pollen collecting wild bees.

In India a large number of their cultivars rarely or never flower (Magoon, 1967). The ~~same~~ problem has been observed within the germplasm collection of several thousand at CIAT, Colombia (Cock, 1972, pers. comm.). Cassava is known to be a short day length plant (Orioli and Blettler, 1967 and Jennings, 1970) but the effect of temperature and its interaction with day length on flowering has not yet been reported.

At IITA most cassava flowers during the period August to January with the peak period October to December, but our collection could be grouped into five categories of flowering: early, intermediate, late, continuous and non-flowering. The effect of time of planting on flowering is now being studied.

The stigma remains receptive for up to twenty-four hours and dried pollen remains viable for six days. Eight to nineteen hours are required for fertilization to occur (Chandratna and Nanayakkara, 1948). Structurally and functionally therefore the cassava flower is adapted to cross-pollination. Both stigma and pollen are very sticky and pollination is effected mainly by insects, but wind and rain may also be agents. Wild bees are the principal pollinators as cassava nectar is very attractive to them. It has been noted that some plants are obviously more attractive to bees than others and this is connected with greater nectar production, sometimes so prolific that it can be found on the petioles. Wild bees are most active under conditions of high temperature, minimum humidity and high

light intensity.

During the first breeding phases, selection among new accessions of M. esculenta, M. glaziovii and M. melanobasis for early and profuse flowering characteristics would further enhance the outcrossing potential. It has been observed that these characteristics are not associated with high yield, but depend on branching habit. Non-branching or indeterminate types do not flower since the inflorescence is carried at the point of branching (normally three branches).

Rogers (1965) reported that M. esculenta is generally less fertile than other species, but under African conditions this does not appear to be the case. Seed matures in about 75 to 90 days (Chandrasatna and Nanayakkara, 1948). The fruit has three locules and 3 seeds and on average 100 seeds weigh 10 g.

Hand Pollination

Flowers are used that, in both sexes, are on the point of opening. Male flowers are collected early in the day and pollinations made during the remainder of the day. Bagging of female flowers before pollination is not practised, unless the particular population is very small and every flower must be utilized. Satisfactory results are obtained when a white paper bag (17 x 9 cm) is used to cover the pollinated flowers and it is much better than the waxed narrow type commonly used by cereal breeders. Seed set readily in most cultivars and families, but there was a 100% failure in hand pollinations

to Llanera, which set seed only when open-pollinated, but could be used as the male parent.

Germination of Seed

Cassava germinates very sporadically over a period of 2-4 months at ambient temperatures and the percentage germination is generally low: about 10-40 per cent. In the past the method most commonly adopted to aid regular seed germination was to crack the seed coat. This produced between 80-100 per cent germination within 15-20 days, but the method was very laborious and many of the seedlings were poor, due to damage to the embryo during cracking. The Federal Experiment Station of Nigeria developed a most successful wet-heat treatment technique which decreased labour costs, reduced seed loss by germination of a large number of seeds of uniform stand over a short period of time (Ekandem, 1970; Beck, 1972). However, at IITA unscarified seed, dressed with an insecticide/fungicide was planted directly in the nursery in February/March in shallow drills and kept well watered. At this time of year the soil temperature was within the required range and an irrigation regime ensured constant moisture, resulting in an 80 per cent germination within three weeks. By this technique about 12,000 seedlings were produced in 1972 and about 100,000 in 1973. The only problem with this technique is the profusion of weeds. To reduce weed competition, an experiment on preplanting treatments was conducted in order to shorten the days from planting in the field to seedling emergence. A presowing

treatment, using wooden flats filled with sieved soil, kept well watered and held outdoors resulted in a uniform 85 per cent germination within 9 days after planting. A convenient and successful (80-90% germination) method for small experiments is to plant untreated seeds in peat pots held in black plastic flats or wooden flats. These, if kept well watered, grow equally well outside or in the hotter screen houses.

From a series of experiments on seed germination, it has been proved that light and drastic changes of temperature are not required for successful germination, but that a soil temperature of between 30-35°C and regular moisture are essential.

Male Sterility

Male sterility has been reported as being very common in cassava (Cours, 1951; Capiupin and Bruce, 1955; Jennings, 1963; Moh, 1966; Magoon, 1967). It has been suggested by Martin (1970) that male sterility could profitably be utilised in the hybridization of cassava. We do not regard this to be a useful procedure, since incorporating this factor would take some time, and technical difficulties might arise. We prefer to produce the required hybrid seed by emasculation of the female plants. Also, since self pollination is rare, the required hybrids can be produced if a population consisting of a single plant of each clone is planted in several isolated breeding plots. Unlike corn, which requires a large amount of hybrid seed for economic production, cassava relies on vegetative propagation. However, male sterility might be worth considering if true seed was to be used in commercial cassava production on a large scale;

but this is not feasible at present.

Genetics in Relation to Breeding

There is little published information on cassava genetics. Cassava has the chromosome $2n = 36$ (Perry, 1943; Magoon, 1967; Cruz, 1968; Abraham, 1970; and Ene, 1972), and is probably an allopolyploid (Jennings, 1970; Ene, 1972). Abraham (1970) produced several tetraploids ($4n = 72$) which gave a poorer yield than the original diploids, and his triploids ($3n = 54$) were superior to the tetraploids.

Doughty (1958) and Jennings (1970) reported that resistance to cassava mosaic is multigenic. Based on data obtained from about 10,000 segregations for 72 families, it appears that resistance is under genetic control by quantitative genes (Hahn and Howland, 1972). From our seven parent diallel cross, it appeared that resistance to cassava mosaic is a recessive character and has a high heritability of about 60 per cent.

HCN content appears to be regulated by a recessive minor gene complex. A cross between two cultivars of low HCN content produced plants having a much lower content than either of the parents, but the frequency was very low. The offspring from selfed low HCN plants did not show a high enough frequency of low HCN plants to support the theory that this characteristic is governed by a few major recessive genes. It should be possible to develop cassava having a much lower HCN content than at present through identifying the genes associated with this factor.

Plot Size and Replications

From a review of the literature Thompson and Wholy (1972) have concluded that a minimum of 16 and a maximum of 32 sample plants are needed to give a reliable estimate of yield and have suggested four replications as a minimum.

We applied the method employed by Hatheway (1961) to determine a convenient plot size and number of replications for the experimental yield data of the net plot, excluding the border. In the experiments, cassava was planted at 1 x 1 m spacing. The true difference expressed as percentage of the mean is 13.7% for the combination of 16 m² plot and 4 replications, but in order to have about the same true difference for a plot size of 8 m², 8 replications would be required and for a plot size of 32 m², 2-3 replications would be required. In order to conduct yield trials of 10 varieties in the most convenient way a plot of 4 x 12 m with four replications harvesting only the central 2 x 10 m net plot appeared to be the most satisfactory. The combination of plot size and replication may vary, depending on soil uniformity and the spacing used, the precision required and the availability of land and research funds.

BREEDING METHODS

Several conventional methods have been used in cassava breeding, but those systems which have been recently developed and most successfully used by breeders of other crops have rarely been applied to cassava.

Once the breeding objectives are defined, a plan will be required which will exploit the variability and genetic potential of breeding populations to provide us with a rapid and efficient method of evaluation and selection of our material.

Our short term objective is to collect and evaluate local cultivars and to hybridize amongst the selected ones. On this basis it is easier to find cassava varieties that will complement each other and produce good hybrids than it is to break linkages and obtain all the favourable genes and gene combinations into one variety.

Conventional Breeding Systems

The early techniques, carried out by all the cassava growing countries which had research facilities to do so, consisted of:

1. Collection and observation of as many local cultivars as possible.
2. Selection of the best cultivars for immediate use and for producing hybrids.
3. Selection of the best plants within a population.
4. Comparison of yield potential and other important agronomic traits.
5. Evaluation of the best selections in local and district trials, followed by general distribution.

Conventional breeding systems which have commonly been used are as follows:

1. Plant Introduction and Clone Selection

Much of the initial breeding work was simply the accumulation of germplasm from various sources and selection of the more

desirable types, which were then bulked up and released. This was the simplest and most effective method used by breeders in the initial stages of their program. The collections included both local and exotic cultivars which were evaluated and developed into clones. Thus, the development of present day cassava in Africa is largely due to importation of cultivars suitable for the prevailing climatic conditions and to the requirements of the local people.

Cassava is a crop which is propagated both sexually and asexually and, as we have already said, it is highly heterozygous. Therefore, initial propagation by seed followed by vegetative propagation will result in higher genetic variation and provide good source material for breeding improved varieties by clonal selection. Clone selection involves:

1. Selection desirable individuals for breeding potential in respect of improved botanical and agronomic characters in the first year.
 2. Developing groups or clones and conducting preliminary evaluation of selected ones in the second year.
 3. Conducting advanced yield trials of the most promising and high yielding clones in the third year, and finally,
 4. Carrying out uniform cooperative trials.
2. Intervarietal Hybridization

Since cassava is vegetatively propagated, it is not necessary to regenerate hybrid seeds for every crop since heterosis is already fixed. If a desirable F_1 plant is obtained, it can immediately be issued as a variety and genetic fixation is unnecessary. If, however, the gene or genes which determine the

character is recessive, an F_2 generation will need to be produced and further crossings made between selected plants to make desirable recombinations.

It is necessary to have as large a population of F_1 plants as possible because segregation takes place at this stage and thus provides a source population for further selection. In a vegetatively propagated crop the genetic material used may come from many diverse sources including wild species and those having different chromosomes or genomes.

In intervarietal hybridization, success depends largely on the appropriate selection of parents having high breeding value. Therefore studies on parental selection are of prime importance, but almost no systematic attempts on this have yet been made. It would involve acquiring a good grounding in genetics, breeding techniques and plant physiology in order to study methods, procedures and criteria of selection.

3. Interspecific Hybridization

Incorporation into cultivars of a vast array of desirable genes from related species containing reservoirs of unexplored and useful genes appears to be of prime importance in a cassava breeding program (Magoon, 1967). The entire genus Manihot can probably be considered as a common pool of germplasm from which desirable genes can be drawn for cassava improvement (Martin, 1970). Almost all the related Manihot species can be crossed with cassava (Rogers, 1973, pers. comm.). However, very few Manihot species have so far been used in this way. Only M. glaziovii, M. cattingea, M. saxicola, M. melanobasis and

M. dichotoma have been used for breeding; for resistance to cassava mosaic and insect attack, for high protein content and drought tolerance. The incorporation of resistance to cassava mosaic by crossing it with M. glaziovii has been particularly successful. It has recently been observed within our screening nursery that this interspecific cross also produces a high degree of resistance to cassava bacterial wilt (Xanthomonas manihotis). It is thus anticipated that a tremendous potential exists for obtaining from other Manihot spp. many economic characteristics which are not found within M. esculenta.

However, the methodology of accomplishing such an introduction of these traits, which are frequently quantitative in nature, into cultivated cassava needs investigation. Backcrossing, followed by selection, has been used extensively (Koshy, 1947; Abraham, 1970; Magoon, 1970; Jennings, 1970; and Beck, 1971), to introduce new genic sources from related species. Two or three backcrosses to adapted cultivars were made, in general, in order to incorporate the resistance to cassava mosaic disease of M. glaziovii, but except for this resistance no overall improvement in cassava was achieved.

There is a great need for breeders to develop a methodology to introgress exotic germplasm most efficiently into their breeding populations, recombine simultaneously among genes from more than two germplasm sources and retain desirable gene complexes built up via past breeding. This is particularly necessary for a breeder who wishes to raise the efficiency of selection by introducing desirable genes from exotic germplasm,

increasing genetic variation of desirable genes and improving chances of recombination in the populations.

The major problem of utilizing exotic germplasm is how to effect the integration of the special features desired from the wild forms in a sufficiently short time to make the effort economically feasible.

Mackey (1963) proposed a modified convergent crossing that might be worth considering as it provides more opportunity for retaining good gene complexes and combinations already present in the current elite adapted varieties; and for the inclusion of any desired percentage of unadapted germplasm in the breeding population. The adapted germplasm in a given convergent cross may come from one, several, or many adapted varieties. This approach has been used in our breeding program to incorporate the resistance of M. glaziovii to both cassava mosaic and bacterial wilt into adapted local cultivars. Three-way crosses instead of single crosses have been effective for introgressing new germplasm into breeding populations (Hahn, 1970). Efron and Everett (1969) suggested making a series of hand crosses between adapted and exotic material, and growing out the hybrids as a population, with natural random crossing in subsequent generations. Population improvement, which will be discussed later, could be a useful and effective approach in this respect.

Population Improvement

A number of cassava breeders have already recognised the importance of improving base populations in order to provide

more desirable sources of new genotypes. As cassava is normally cross-pollinated, random mating usually takes place resulting in a high degree of seed setting, although in a random population one might expect a certain degree of self-pollination. Therefore, population improvement schemes can be specifically adapted to cassava. It should be borne in mind, however, that since flowering times differ with individuals, complete parental representation might prove difficult.

As we look ahead to the next decade, we are convinced that our greatest yield advances in both quantity and quality in cassava are likely to come from the use of improved populations developed through cyclic selection and recombination procedures.

Breeding schemes are needed to provide continuous genetic upgrading of the breeding populations through new germplasm introgression, selection and opportunities for continuous genetic recombination.

Cassava breeders are fortunate in dealing with a plant the flowering mechanism of which makes it very easy to obtain a large number of recombinations, with minimum effort, and ease of vegetative propagation readily provides quantities of planting material from the one genotype. Thus populations can be converted into random mating populations which can be improved by the use, either directly or with modifications, of the recurrent selection programs and cyclic breeding systems currently used successfully in corn. The effectiveness of recurrent selection on population improvement has been reviewed by Sprague (1966) with a discussion on different methods of selection for population improvement.

Various methods used in breeding systems for population improvement were summarized by Gardner (1972) as follows:

Intra-population improvement methods:

Mass selection

Half-sib family selection

Full-sib family selection

S₁ family selection

Inter-population improvement methods:

Half-sib reciprocal recurrent selection

Full-sib reciprocal recurrent selection

Major genes that affect quantitative traits, resistance to cassava mosaic for example, are relatively easy to substitute into populations and their effects are easily identified. However, substitution is difficult of the so-called polygenes, which are the ones we hope to change by recurrent selection and recombination. Recurrent selection has been shown to be effective in increasing yield as well as in improving the more highly heritable agronomic characteristics. The methods of selection listed above and modifications of them have been proposed and used for this purpose. However, the particular method to be used for cassava breeding should be chosen on the basis of the facilities and funds available and the variation, both genetic and environmental, in the materials under selection. Breeding systems for population improvement vary greatly in technique and in the length of cycle.

Population improvement may take many forms, but in each case the effectiveness of the type of selection is based on the utilization of additive gene effects (Sprague, 1966). Population improvement results from a conceptually simple process - the

substitution of one allele for another in the population. Inferior alleles are replaced with better ones at each locus, and alleles that interact favourably with each should be accumulated at different loci (Gardner, 1972). The frequency of good genotypes is increased, the mean is raised and from the improved population clones can be selected that are better than those which could be expected from the original population.

When improvement in combining ability is aimed at through population improvement, both additive and non-additive effects **must** be considered. Hull (1945) assumes an additive effect to be absent in recurrent selections for specific combining ability. If this assumption were valid, progress in selection would depend on dominance and epistatic effects. Epistasis, particularly of the additive types, is likely to be an important factor in the hybrid performance of vegetatively propagated cassava. Our base population needs to include those alleles at each locus that act^{and}/interact with alleles at other loci to give the best possible genotypes.

The cyclic breeding systems for population improvement all involve evaluation, selection and recombination. Plant breeders use one of the various breeding systems that involve the following (Gardner, 1972):

1. Observation, testing or some other form of evaluation.
2. Selection of superior phenotypes (individuals or family).
3. Recombination of superior units selected.
4. Development of new units for evaluation prior to beginning another cycle.

Local quarantine regulations prohibit the use of vegetative cuttings as a method of distributing improved varieties. The exchange of superior genotypes in the form of true seed which are improved through population improvement appears to be the only feasible method of helping the many national cassava breeding programs. IITA should be the centre for such a collection of true seed containing large genetic variation and potential. We should consider two types of population improvement: (1) a short-range program to make rapid progress in the immediate future and a long-range program which may start at a lower level but advance to a higher level over a longer period of time, (2) a long-range population improvement in which more genetic variability is needed and during the program any new favourable plant could be extracted for additional testing at each cycle of improvement of the base population.

The first step is the polycross method conforms to the principle originally set forth by Vilmorin, that the best criterion of the breeding value of a selected plant is the performance of its progeny. Open-pollinated seeds produced from selected plants flowering in an isolated plot where random pollination will have occurred are used in field tests to evaluate their breeding value. The genotypes of the selected plants are propagated through selfed seed or by clones which can be established without difficulty from stem cuttings. The outstanding plants, as indicated by the field performances of the open-pollinated progeny, are intercrossed to produce a synthetic variety, or possibly a clone for a second cycle of selection.

Repeating the breeding cycle would constitute recurrent selection (Coons, et al. 1955).

Bearing in mind the life cycle, propagation - sexual and asexual - and flowering in relation to outcrossing of cassava, we now discuss specifically the selection systems that might be applicable and effectively used for population improvement.

Mass Selection

Mass selection for some traits has been successfully used in corn. However, in cassava, where height and coverage varies and plants may grow very tall and occupy a large space, considerable intergenotypic competition exists and mass selection might not be too effective. Frequent growth failure of some plants also contributes to the competition problem. In our varietal competition study, tuberous root yield was strongly affected.

Mass selection is a more efficient method of improving characters with high heritability. Selection on a single-plant basis would thus not effect an improvement unless the trait had exceptionally high heritability e.g. mosaic resistance.

Mass selection has several desirable features: (1) One cycle of selection per generation, (2) simplicity of operation and minimum labor requirements, and (3) it can be expanded at will without any necessary increase in rate of inbreeding (Sprague, 1966). Mass selection requires no hand pollination and has a small land requirement. However, mass selection does not progress as rapidly as some forms of progeny testing at several different

locations (Eberhart, et al. 1967).

One trial consists of about 1,000 plants, each from a different selected clone and planted in isolation. Male flowers of agronomically undesirable plants are removed prior to flowering so that other traits associated with yield improvement will be emphasised. Equal quantities of seed of each cross will be bulked and used to initiate the populations. As this is an initial improvement stage, a large size population was planted in order to include as wide a genetic variation as possible from many different sources. The size of population will eventually be reduced as experience and basic information related to evaluating promising clones accumulates.

Martin (1970) suggested the use of mass selection for population improvement for developing a gene pool, and for overcoming sterility. Development of random mating populations on a wide genetic base would create a dynamic and powerful germplasm reservoir, improved continuously by mass selection.

Half-Sib Family Selection

Half-sib family selection would be a very easy system that might be most appropriate for use in cassava, although it would have a lower efficiency compared with full-sib family selection. This selection has been extremely effective for characters of high heritability. However, a half-sib family system combined with individual plant selection within families has given excellent results for improving yield of corn (Webel and Lonquist, 1967).

Plant-row selection as proposed by Lonquist (1964) involves half-sib family selection. The modified plant-row method proposed by Webel and Lonquist (1967) is essentially a combination of half-sib progeny testing and mass selection. Thus selection was based on half-sib family means, and subsequently on individual phenotypes within selected families. This method should also be effective if trials are conducted in 3 to 4 locations using a small plot size and only 2 replications per location.

Plant-row selection requires only one generation per cycle and no hand pollinations are necessary and it includes in a one generation cycle: (1) yield trial evaluation between progenies, (2) individual plant selection within progenies and (3) recombination. Large numbers can easily be handled. The plant-row selection could provide for more rapid intensification of favorable genes, or gene complexes of the additive sort, without excessively high rates of inbreeding. It will provide the retention of much of the favorable genetic material present in the original gene pool, which is desirable from a long range point of view. The problems associated with differentiation of genotypic differences can be overcome to a certain degree through the use of progeny evaluation procedures (plant-to-row). In this trial the elimination of undesirable male plants can provide the selection pressure for agronomic traits, so that selection among and within plant rows can be made exclusively for yield. Through constant selection pressure based upon more reliable evaluation procedures, considerable modification of the

population in the direction desired should be possible. When the genetic variance remaining is largely of dominance and epistasis, the extraction of clones for F_1 hybrid combination can be used to further enhance productivity.

About 50 families out of about 900 have been selected, based on origin, resistance to cassava mosaic, conformation, root characteristics and yield potential. They were planted each in rows, in two replications, in an isolated plot for a dry season trial. The same set of materials has been planted in fertile soil, ^{and} they will also be planted in the wet season. Bulked root stocks of these families were interplanted to provide pollen, discarding those having undesirable root characteristics and root rot. Selection among families will be made, based on average family performance in the trials, and also selection of desirable individuals within the selected family. The male flowers of the plant rows will be removed to prevent sibbing and consequently inbreeding within the plant-row. Undesirable pollen parents will also be removed before they flower.

Full-Sib Family Selection

Even though variation among entries is large this selection system is practically and technically difficult to apply to cassava breeding as it requires two generations to complete a cycle and it is difficult to make full-sibs and to obtain sufficient seed.

S₁ Testing

S₁ testing per se is a theoretically useful method since the variability among lines is increased by inbreeding. However, this system is not suitable for cassava since it requires three generations per cycle and it is difficult to obtain sufficient selfed seeds for replicated trials in several locations or environments.

It was suggested by Koshy (1947) and Abraham (1957) that "locked up variability" could be used for selection, and that evolving homozygous lines for the purpose of exploiting hybrid vigour offered the most promising line of approach in cassava improvement. Abraham (1957) and Martin (1970) indicated that inbreeding can be practical and useful, since it increases uniformity thus facilitating more effective evaluation. Through selfing, both undesirable and desirable recessive characters could be identified. However, Abraham (1957) reported several practical difficulties in selfing, such as variable time of flowering and difference in time of mating of male and female flowers in a plant, rapid loss of yield, poor flowering and vigour, pollen sterility etc, after only two or three generations of selfing.

Reciprocal Recurrent Selection

This system was designed to improve the performance of the cross of two populations, or of the hybrids of lines or clones derived from them. Of the two systems, half-sib reciprocal

recurrent selection, which was originally proposed by Comstock, et al.(1949), appears to be themmore applicable to cassava.

Comprehensive Breeding Scheme

This breeding scheme is a modified recurrent selection proposed by Eberhart, et al.(1967) as an approach to continuous population improvement through new germplasm introgression, selection, and genetic recombination. The scheme consists of the following:

1. Local and exotic germplasm sources (usually varieties) are evaluated and undesirable sources eliminated.
2. The selected sources are composited into two or more populations, each to contain considerable genetic variation for traits to be improved, with the different populations being relatively unrelated.
3. Recurrent selection would be applied within, between and among populations to increase the frequencies of genes that will maximize the population performance and population-cross performance.
4. The release of either synthetic varieties, variety crosses or hybrids.

This scheme could be applied very practically to cassava breeding. Harrison (1973, pers. comm.) suggested developing two different cassava populations; one from African sources and the other from Latin American sources, after each had been crossed with sources resistant to cassava mosaic and bacterial wilt, and then following the comprehensive breeding system outlined above. The cultivars or clones going into each composite should be carefully selected based on their performance which could be tested by crossing with each other in complete or incomplete diallel fashion.

Basic information on the performance in respect of various important agronomic traits of several promising clones had been obtained from our diallel cross and ordinary crosses. Recombining populations have been planted out in several isolated plots as a follow-up. This approach will enable us to utilize the heterosis which might be an important feature in future breeding and use of recurrent selection in at least 2 populations offers the future option of using specific combining ability, in addition to upgrading the population by incorporating and recombining desirable genes of exotic germplasm from Latin America into African cassava.

Population Size, Number of Generations and Selection Pressure

No critical information is available regarding the size of population that should be saved at each cycle of improvement. This will depend on selection schemes, variation desired, funds and land space available. Eberhart, *et al.* (1967) suggested that the total number of corn plants saved each cycle from all entries should be fairly large, perhaps 800-1,000, to prevent loss of favourable genes due to a finite population size. Jones (1965) suggested that approximately 500 plants of sweet potato per generation should be sufficient.

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to three generations of random mating should be used to achieve synthesis in a population before initiating selection (Gardner, 1972). Eberhart, et al. (1967) suggested that populations should mate randomly for several generations before recurrent selection is begun, to allow linkages to break up. Selection for simply inherited characteristics should be avoided until after four to five generations of intermating, since such selection would tend to fix chromosome segments and thus reduce the frequency of effective recombination (Hanson, 1959). This is particularly true and important when exotic germplasm is involved. However it might be desirable to start selection earlier than this. Harrison (1967) proposed the "Irish method," a modification of the plant-row method: mass selecting individual plants within rows, but no selection between rows. By this method he was able to improve corn successfully without random mating before mixing a new composite population.

Beck (1971) reported that his cassava breeding program contained one basic fault, the reason being that he could not properly evaluate the yield potential of his breeding clones, because of the interaction of yield with cassava mosaic resistance. His problem might be explained in terms of population size, selection pressure and number of generations of random mating. He did not use population improvement schemes in his cassava breeding program and was dealing with a small size population, even for a conventional breeding method of a vegetatively propagated crop. He overemphasized resistance to cassava mosaic and applied too heavy a selection pressure in

screening for resistance to the disease while he was introgressing the resistance from Manihot glaziovii into cultivated cassavas. This might result in reduced levels of recombination among desirable genes in his breeding population except for high resistance to mosaic. Moreover, he did not use an efficient and appropriate breeding scheme for introgressing exotic germplasm from related species into cultivated clones of cassava.

Phenotypic differences on which selections are made are the result of interaction effects of environment with the particular genotypes. Phenotypic differences are therefore no guarantee of genetic differences. A plant breeder's success in varietal improvement is determined in no small measure by the precision of the screening devices used to select superior plants. Characters with low heritability such as yield, are particularly vulnerable to environmental effects. Selection pressure and stage of selection, therefore, will vary with the characters to be improved. Eberhart et al. (1967) reported an intensive selection at a level of 5-10% in the first cycle and 25-50% in the second and third cycles of their population improvement in corn.

PROGRESS IN BREEDING PROGRAM AT IITA

In 1972, about 12,000 seedlings were raised comprising three main groups: (1) open-pollination among Nigerian local cultivars, (2) hybrids among the selected Nigerian cultivars, and (3) introductions from Latin America and Asia. They were

screened for resistance to diseases, especially cassava mosaic and bacterial wilt; evaluated for reaction to insect attack, plant conformation, and tuberous root characteristics. From these about 12,000 promising individuals were selected and planted out in rows to conduct a preliminary evaluation for yield potential, dry matter percentage, starch content and quality, and various other agronomic traits. Further tests for the characteristics previously evaluated are to be made. Many clones resistant to cassava mosaic and bacterial wilt were obtained from groups 1 and 2 but most of the plants from group 1 were highly susceptible. About 1,000 individuals representative of each selected clone were planted in an isolated plot to produce the base population for mass selection and comprehensive breeding schemes.

About 100,000 seedlings were raised in February-March of 1973. They were screened for resistance to cassava mosaic and for acyanogenesis, and a large number of individuals having resistance to the disease and low HCN were obtained. In September-October, about 50 promising families from various sources were selected based on their performance and desirable attributes and planted out in isolation to start a half-sib family selection scheme. These were planted in replicated trials interplanted with basal root-cuttings of those plants showing the best root characteristics (short, fat, compact and uniform). A second selection of about 3,000 individuals was made amongst all families primarily on conformation. However, in the case of **certain** exotics considerable selections were made of the vigorous plants irrespective of conformation in order to provide as

many different sources of genetic diversity as possible in the population. They were planted in rows for further evaluation for improved agronomic traits in the dry season. Further selection will be made in March-April for wet season evaluation. About 1,000 root stocks selected out of the first 3,000 selections chosen for desirable characteristics have been planted out in isolation to provide a germplasm reservoir and to apply various selection schemes for population improvement.

It is now known that resistance to cassava mosaic is controlled by quantitative genes, appears to be recessive and has a high heritability to of about 60%. HCN content appears to be regulated by a recessive minor gene complex, and resistance to cassava mosaic and bacterial wilt appears to be associated - the resistance to both coming from Manihot glaziovii. It appears that tuberous root characteristics are highly heritable and that selection for them is possible at the seedling stage. Significant variety-season interaction and varietal competition have also been noted.

ACKNOWLEDGEMENT

The authors express their appreciation to Dr. K. O. Rachie and Mr. M. N. Harrison for their valuable suggestions, criticisms, and thorough reading of the manuscript.

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CURRENT TRENDS IN CASSAVA RESEARCH

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ABSTRACT

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 program 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 headings of "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 multidisciplinary approach to cassava research and a greater research input are recommended.

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 nacional 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 reconocido 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 alimento para humanos y animales, su enriquecimiento y fortalecimiento, toxicidad, utilización en la industria, economía de su producción, mejoramiento genético, enfermedades y pestes, factores que afectan su rendimiento y sistemas mejorados de información". Se recomienda un mayor esfuerzo investigativo y un enfoque multidisciplinario en la investigación sobre mandioca.

RÉSUMÉ

Le manioc, une culture oublié pendant des années par les investigateurs, reçoit actuellement une attention particulière de la part des centres de recherches nationaux et internationaux; jusqu'a present, le plus grand programme d'investigation sur le manioc se fait au Centre International pour l'Agriculture Tropical (CIAT) en Colombie. Il n'a été 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 recentes et de nombreux travaux actuellement en procès et qui n'ont pas encore été publiés ont été décrit sous le titre: "Le manioc comme nourriture humaine et animal, son enrichissement et renforcement, toxicité, utilisation industrielle, economie de sa production, progrès génétique, maladies, pestes, facteurs qu'affectent son rendement et des méthodes meilleurs d'information". On recommande l'utilisation d'un plus grand effort investigatif et un aperçu multidisciplinaire dans l'investigation sur le manioc.

CURRENT TRENDS IN CASSAVA RESEARCH

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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 (1970) 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 program 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 programs.

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 dramatically. CIAT now has a team of scientists from nine different disciplines back-stopped by basic research in Canada dealing with eight specific problems, the total annual budget of this joint program 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 program 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 has ultimately to be transmitted via national institutions, which have traditionally paid very little attention to cassava except in the case of India, where for the last decade there has been^a strong Central Root and Tuber Crop Research Station, albeit with a rather tight budget. Fortunately other good new national programs 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 (Anon 1972 a) funded by the private sector and counselled by Normanha. Stronger (and in most cases new) national programs are also under discussion in Peru, Malaysia and Thailand and in some African countries, additionally the private sector (Brascan in Brasil, 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 (Phillips 1973) coupled with the general lack of knowledge about the crop in spite of its phenomenal energy producing potential (Coursey and Haynes 1970) in a hungry world, appear to have led to some re-thinking 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 with many of the relatively small group 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 the 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

The most important use of cassava is as a 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 (1973) has projected that by 1980 consumption will rise to about 71 million tons.

Table I indicates those countries in which human cassava intakes appeared to be highest in the mid 1960's. These national data do disguise regional differences within countries. For example Nicol (1952) 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 (1961) surveys in Java indicated areas where the calorie intake from cassava exceed 63%. Normanha (1970) 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 (Coursey 1973). 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 (Akinrele, Ero and Olatunji 1971). A preliminary report from Ghana (Dovlo 1972) 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 (Dovlo 1972). Miche (1971) 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 1973) but much still remains to be done to incorporate them into a high yielding ideotype.

Some promising progress has been made in the storage field in which the literature has recently been reviewed by Ingram and Humphries (1972). 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 received some publicity in Colombia recently (Anon 1973)

where it is claimed to have considerably extended shelf life.

More recently Booth (1973 a) has reported on a technique which extends both post-harvest on-farm storage and shelf-life. In another paper (1973 b) Booth has stressed the importance of mechanical damage in post-harvest losses, this confirms the observation of Averre (1967) that vascular streaking of cassava roots commenced at cut surfaces. Averre's (1967, 1970) claims that vascular streaking is enzymatic in nature received some support from the identification by Czyhrinciw (1969) of peroxidase and catalase in fresh cassava. Montalido (1973) 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 to be warranted.

ENRICHED AND FORTIFIED CASSAVA

Because of its low protein content the nutritional enrichment of cassava has received a great deal of attention. Some work has been carried out with enriching traditional products such as gari (Akinrele 1967) and cassava soups and porridges (Mosha 1972), however prime attention has been given to fortification of cassava flour with soy protein isolate or soya grits. This work has been the subject to extensive research in Brazil (Anon 1972 b) 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 one 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 Tecnologia Agrícola e Alimentar in Rio de Janeiro and the Instituto de Investigaciones Tecnológicas in Bogotá. It 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 (Kim and Rutter 1968, Pringle, Williams and Hulse 1969, Perten 1970, Dendy, Clark and James 1970).

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 Hosney et al (1971) and the role of gluten substitutes examined by Lagendijk and Pennings (1970) and by Rasper, Mak and de Man (1972) who have studied the structural development of dough and its visco-

elastic properties in cassava fortified mixes. Research under way by Bushuk (1973) in Manitoba is showing promising progress towards the development of a simple process of mechanical mixing which both simplifies and improves the quality of the flour containing cassava. Technical and economic issues still remain to be resolved in the composite flour field, but present and projected demands and the relative prices for wheat and cassava do seem to indicate that cassava-fortified flours could play an increasingly significant role in the future.

The potential for using cassava as a substrate for the production of fungal protein was reported on by Gray and Abou-El-Seoud in 1966 and later expanded upon by Stanton and Wallbridge (1969). More recently Strasser, Abbott and Battey (1970) described a pilot plant process for which they prepared preliminary cost estimates for a 10 ton/day plant. In the last year Gregory and Reade (1973) 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 from cassava at a relatively low cost under conditions which may be practical at a field scale in cassava producing areas. Related work is also under way by Hutagalung and Stanton in Malaysia using a solid cassava substrate.

CASSAVA AS AN ANIMAL FEED

Although the 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 livestock oriented. The work of Gregory and Reade is particularly related to the use of residues from cassava (tapioca) starch factories. 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 (1971) 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 from 2 to 15% 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 in 1957 and more recently the work has been spear-headed by Maner and his associates at CIAT, by a group of workers at the University of Malaya and by Müller in Singapore.

It is of interest to note that much of this research is being done in countries that are not major cassava producers in world terms and that 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 his livestock. European use of cassava in animal feeds has resulted from its favourable

price, compared to feed grains, in countries deficient in feed energy. At present cassava seldom comprises more than 10% of feed compounds 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%. 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 (1971) found that cassava meal substituted for corn up to levels of 60% in broiler rations providing that the diet was balanced and that at higher levels of substitution the cassava was pelleted. Nutritional problems arose when the fibre content of the cassava meal exceeded 3.5% and economic difficulties when the cassava meal price exceeded 67% of the price of corn. Somewhat similar findings were reported in Mexico by Tejada de Hernández and Brambila (1969) who were able to use up to 50% cassava meal in rations for young chicks which had similar growth but lower feed efficiency than chicks on corn starch. The authors commented on the wide range of HCN levels presented in their rations and the uncertainty regarding its nutritional significance. A similar finding was reported on by Jalaludin and Oh (1972) who fed very high levels of HCN to laying hens without producing toxic effects.

Hamid and Jalaludin (1972) used cassava successfully to replace corn at levels of up to 60% in 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 was a limiting factor on high cassava rations. The carotene level might, however, be of less significance in areas where yellow cassava is produced (Guimaraes and Cresta de Barros 1972).

The use of cassava root meal in both grower and layer diets has been reported from Hawaii (Enriquez and Ross 1972) 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 (Maner 1972, 1973) who have used up to 60% 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 the detoxification of HCN. Hew and Hutagalung (1972) 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% methionine to a 50% 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 HCN levels by forming glyconohydrin and improving palatability) improved both daily gain and food conversion. From the economic standpoint the fully supplemented 50% cassava ration gave lower (10%) daily gains at a cost per kg of gain that was

less (3%) than a corn-based ration.

Müller, Chou, Nah and Tan (1972) recommended the use of cassava meal in pig rations when the price of a 85% cassava meal/15% 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% in starter rations with 5% fibre, to 75% in finisher rations of 2.8% fibre and containing only cassava, soy bean meal and minerals.

Further recent reports using cassava for swine feeding originate from Fiji, (Teleni 1972) and Venezuela (Chicco et al 1972). A 40% cassava 20% 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 the source of the reduced availability of zinc (Maust, Pond and Scott 1972).

The literature regarding cassava as a ruminant feed appears to be very sparse although Chicco et al (1971), Shultz et al (1970) and Shultz and Chicco (1970, 1972) have carried out extensive studies on the use of cassava in conjunction with urea in both bovines and sheep. In Malagasy, Serres (1969) has reported on the use of cassava roots and leaves as a component of rations for intensive finishing of cattle. Serres and Tillon (1972) have also reported on the production of cassava root silage for pigs (fed 3 Kg/day) and cattle (fed 5 Kg/day). Extensive trials on the use of cassava root silage as a component of swine rations have been conducted by Maner. Low protein levels presented a problem and attempts to raise this by microbial action have not been successful (Gregory and Reade 1973).

Serres's work on using cassava leaves for cattle was pre-dated in 1952 by Echanti who was looking for a substitute for alfalfa meal. This work has been followed up in chickens and quails by Ross and Enriquez (1969) and in pigs by Lee (1972) and Lee and Hutagalung (1972). It appears that in both pigs and poultry 20% cassava leaf depresses both liveweight gain and feed conversion but the addition of sodium thiosulphate, methionine and molasses and/or vegetable oil partially corrects these depressions. Further studies on cyanide content (Chew 1973) and water soluble protein (Foo and Chow 1973) of cassava leaf have been carried out to help elucidate its nutritional value.

Additional work on this seems to be necessary since Juarez (1955) 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) seem to suggest that with appropriate management even higher leaf yields may be feasible. Since leaf protein values are reported to be between 20 and 30% on a dry matter basis (Rogers 1959), the possible role of cassava leaves as food or feed may need re-examining. Eggum (1970) has already shown that the digestibility of cassava

leaf protein in rats was 70-80% although the biological value of the protein was only 44-57%. However the addition of methionine to the diet raised the B.V. of the cassava leaf protein to 80%. A similar result was obtained by Adrian and Peyrot (1971) when adding cassava leaf protein to cereal diets.

CASSAVA 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 to be responsible for both acute and chronic toxicity in humans for some time, 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 (Osuntokun 1973), but that in the presence of marginal iodine and low protein intakes, high cassava diets may be a permissive factor in the development of goitre and cretinism (Ekpechi 1973, Ermans et al 1973). 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 (Maner and Gomez 1973).

A recent workshop reviewed the subject of chronic cassava toxicity relating the biosynthesis of cyanogenic glucosides (Butler, Reay and Tapper 1973, Conn 1973, Nartey 1973), the agronomic and physiological aspects of cassava toxicity (De Bruijn 1973 a), and detoxification mechanisms (Coursey 1973, Oke 1973) to the theme of human toxicity.

The workshop proceedings (Nestel and MacIntyre 1973) contain 18 papers and a number of recommendations for future lines of research. Amongst these was the need to ensure that breeding for low cyanide varieties would not increase the susceptibility to pathogens and pests. The techniques and problems of adequate assay was also a subject that received considerable attention since the cyanide in cassava results from the breakdown of relatively stable linamarin and lotaustralin whose own toxicity is unknown. There have been several recent papers (Esquivel and Maravalhas 1973, Sadik 1973, Zitnak 1973) dealing with cyanogen assay in cassava roots and leaves, but the relevance of rapid assay techniques to the problem of toxicity appears to require further clarification, especially since both CIAT and IITA are selecting for low cyanogen levels.

Cassava has also been incriminated in problems of aflatoxicity 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 (Boshell 1968).

More extensive studies with cassava starch in Thailand and Hong Kong (Shank et al 1972) and in fermented cassava from Dahomey (Toury and Giorgi 1966) have also shown the presence of aflatoxins and an aflatoxin-like factor has been recorded in India (Nagarajan, Bhat and Tuipule 1973). In a field study in Uganda (Serck - Hansen 1970) 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-amylose high-amylopectin content of cassava starch give it unusual viscosity characteristics and great dimensional strength, these find a number of specialized uses (Ayras 1972). The characteristics and behaviour of this starch have been studied in great detail by Rasper (1969 a, 1969 b, 1971); Banks et al (1972); Srivasta and Patel (1973); Velikaya and Nguen (1971), and by a number of Brazilian workers (Rosenthal et al 1972, Mors 1972).

Cassava can be hydrolyzed to produce glucose (Park and Lima 1973) and a feasibility study for a cassava based glucose industry has been carried out in Nigeria (Dina and Akinrele 1970). It can also be converted to alcohol (Teixeira 1950), 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 (Evans and Wunzburg 1967). Cassava stalks have also been used to make particle board (Flaws and Palmer 1968).

The technology for processing cassava has been described in some detail by Grace (1971). By and large 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 (1969) and a pilot solar drier of another type is currently undergoing tests in Trinidad (Springer 1972). The drying characteristics of cassava are also being studied by Roa (1973) who has developed machinery for producing cassava bars (1 x 1 x 0.5 cm) directly from roots. However, none of these new techniques appear to have been evaluated economically in terms of current drying practices for which concrete yards are normally used. 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 (1972) 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 from a ton of fresh cassava whereas for fresh cassava for human use, the Jamaican farmer obtains 2 - 4 times this price (Rankine and Houg 1971) 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 (1972) 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 50 to 200 and to average about 100 (Andersen and Díaz 1973; Brannen 1972; Rankine and Houg 1971; Raeburn et al 1950). 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 (1964) 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% of the total labour costs). For this reason production costs may be expected to rise. Against this it must be taken into account that subsistence yields are often only about 10% 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 varieties 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 mecha-

nization 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 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 creating 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 (1973) and the economics of mechanization by Dulong (1971) who claimed that very high yield levels would be required for mechanization to be economic in the Malagasy Republic.

Andersen and Diaz's paper 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 (1968) and by Phillips (1973) and the processing sector in general by Grace (1971) and more specifically in West Malaysia by Wahby and Eriksen (1969) and in the Malaysian State of Perak by Chye and Loh (1971). 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 Comissão Nacional de Mandioca and by Dantas (1973) 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 (1973) in Malaysia.

At the farm level Diaz (1973) 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 program. 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 of both identifying growth opportunities and attracting new investments. In this context it is of particular relevance to note 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 to work on. Perhaps 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 (1971) and in the reports to the previous and current Tropical Root Crop Symposia by Magoon (1967, 1970) and Magoon and Krishnan (1973).

The main efforts in the plant breeding field 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) the Malagasy Republic (Dulong 1971) and India, where it has been associated with efforts to enhance the protein level of the crop (Hrishi and Jos 1973). Colchine has also been used to induce polyploidy by Magoon et al (1969) and later by Imam (1972), but significant yield responses do not appear to have followed this treatment.

The recent publication by Rogers and Appan (1973) of their monograph on the genus Manihot represents a useful tool for agronomists and plant breeders interested in cassava improvement. The biosystematic work of these authors 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 (de Bruijn 1973 b). Similar but less spectacular increases in yield have been reported from grafting M. flabellifolia onto M. esculenta (Mogilner et al 1967) although according to Rogers and Appan 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 manioc (cassava) use may have pre-dated that of corn. It is pleasing to see a paper on this subject (Lathrap 1973) listed for this meeting. In the same field the evidence regarding the area of origin of M. esculenta as a crop plant has recently been reviewed by Renvoize (1972).

One 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 protogynous nature of the plant and the frequency with which pollen sterility occurs. Efforts to overcome this situation are being made by propagation studies (Krochmal 1973, Wholey and Cock 1973).

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 (Berbee, Berbee and Hildebrandt 1973, Kartha et al 1973) 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 (IITA 1972). This meeting categorised 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) a mycoplasma - induced disease of which at least 3 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 (1973) has recently established a program which will enable him to look at cassava mosaic from all 3 geographic sources.

A report on Indian mosaic is being presented at this meeting by Narasimhan and Arjunan (1973) and Kitajima and Costa (1973) are reporting on their EM studies with cassava virus and microplasmas in Brazil. The IITA report contains a review of most of the African literature but excludes reference to a paper by Golato (1971) in Ghana and to the most recent contribution by Chant, Bateman and Bates (1971). It also excludes mention of a paper by Ganguly, Raychaudhuri and Sharma (1970) 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 relating to the major bacterial, viral and fungal diseases of cassava has recently been reviewed in some depth by Lozano and Booth (1974). Their review covers most of the work in this field 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 the roots. Little information is available on control measures except in the case of bacterial blight.

The presence of cultivars resistant to some disease conditions is noted, as is the need for more information on host-parasite relationships in order to better understand the nature of this resistance. A similar plea is put forward by Rosseto et al (1973) and it also appears to be relevant to resistance to insects since van Schoonhoven (1973) has noted varietal differences in tolerance to attack by thrips and spider mite. The possibility of relating disease and pest resistance to a chemotaxonomic classification of the CIAT and other cultivar collections is being examined by Grant (1973).

The literature on parasitic nematodes associated with cassava appears rather sparse, in his bibliography Montaldo (1967) lists only two species recorded in cassava. There is, however, a recent reference on this subject from Trinidad (Brathwaite 1972). An up-to-date review of insect and acarid 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 (Bennett 1973) the mite is being studied by Nyiira (1973)

Research on weed control in cassava also appears to be relatively new. Doll and Piedrahita (1973) at CIAT have a fairly comprehensive program which is of particular interest from the standpoint of the relationships between morphology, yield and weed control, especially with respect 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 inter-relationships 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' where 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 (1971) reports 70 tons/ha in the Malagasy Republic, Cock (1973) 47 tons in Colombia and Schmidt and Pereira (1968) 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 from Sierra Leone (Godfrey - Sam - Aggrey 1973); Kenya (Gurnah 1973); Peru (Hoffman 1973) Nigeria (Okigbo 1973, Obigbesan and Agboola 1973) and Colombia (Wholey and Cock 1973) and recent papers on this theme also originate from the Seychelles (Smith 1970) Mozambique (Mota 1970) and Malaysia (Chan 1969).

Amongst the factors influencing yield, one that has been relatively neglected in past research efforts is that of the onset and rate of root bulking. Wholey and Cock found that differences in yield after seven months were caused by variations in the rate rather than in the time of onset of root bulking. However, seven months may be too early to make decisions on yield maximization, Chan found that a number of his varieties yielded significantly higher at 12 months (but not at 14) than they did at 8 months. His current studies involve harvesting at intervals up to 21 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 stake 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 (1970) 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 (1972 a, 1972 b, 1972 c) 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 (Enyi 1973 a) 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 (1971) and Williams (1969, 1971, 1972) and in papers presented here by Cock (1973 a) Cuervo (1973) Natarajan and Rengasamy (1973) and Natarajan and Vijayakumar (1973). It appears that leaf

area index is sub-optimal after six months due to leaf fall although in one variety Cock found that he could compensate for this by raising the plant population as high as 20,000/Ha with an associated increase in yield. However, the application of modern techniques and ideas in plant physiology to cassava research is a very new concept 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 (Krochmal and Samuels 1970) and in one experiment (da Silva and Freire 1968 a) P & K applied before planting depressed survival. On the other hand various authors (Chan 1969; Chew 1970; Cock 1973 a; da Silva and Freire 1968 b; Vijayan and Aiyer 1969; Yong 1970) 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 (1973) in Queensland and by Bates (1973) 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 program (Hunt 1973) 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 (Cock 1973 a), India (Indira and Sinha 1970, Indira and Kurian 1973) New Guinea (Enyi 1973 b) and Trinidad (Ferguson 1973). Ketiku and Oyenuga (1972) have traced the changes in the carbohydrate constituents of cassava roots during growth. The starch level peaked (81% of the carbohydrates) at 8 months and sugars reached their peak concentration of 5.7% (of which 69% 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 (1971) 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 (Montaldo 1967, Henain and Cenoz 1969, Ingram 1969, Anon 1972 c), in addition to some reports with lengthy lists of references (Grace 1971, Hendershott 1971). 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 (Monge 1973). A cassava thesaurus has been prepared (Leatherdale 1973) 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 close to one hundred scientists who are actively engaged in research on cassava at the present time.

This is a big change from the situation only 3 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 a 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 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 programs.

In human resource terms, 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.

TABLE 1. HUMAN INTAKE OF CASSAVA IN 14 COUNTRIES 1964-66

(Source: FAO Food Balance Sheets 1974 - 66)

	Human Population (million)	Cassava as % Total caloric Intake	Cal/day From Cassava	Cassava Per year (kg)
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 avg. (14 countries)	-	19.4	374	124

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

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7

CIAT'S CASSAVA INFORMATION CENTER 1/

Fernando Monge, Ph.D. 2/

1. Introduction

The Centro Internacional de Agricultura Tropical, CIAT, is directed toward the agricultural and economic development of the lowland tropics. The ultimate goal is to assist directly and significantly in the economic development of the countries of the lowland tropics with particular attention initially to Latin America.

CIAT seeks to achieve this goal through research, training, and stimulation and strengthening of national capacities in those areas.

The specific action targets of CIAT programs are:

1. Agricultural Development, as indexed by increased productivity per person and per unit of area, as well as increased output of the basic food commodities of the area served.
2. Institutional Development, as evidenced by increased willingness, technical competence, and organizational ability of national institutions to cope with continuing problems related to agricultural and economic development in the lowland tropics.

CIAT concentrates efforts and resources on six agricultural commodities for lowland farming systems -- beef, cassava, beans, swine, rice, and corn. In addition, CIAT is also concerned with overall agricultural production systems for these tropical areas.

1/ Paper presented to the 3^d International Symposium on Tropical Root Crops, December 2-9, 1973. IITA, Ibadan, Nigeria.

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Development of these systems, however, takes into account relevant economic and other social issues. Economists consider not only the profitability of production practices on the farm, but also matters of inter-commodity complementation, of public policy as it affects development of tropical areas, and of marketing. Of particular concern is the suitability and adaptability of technology to the small farmer.

Consequently, CIAT's systems approach to solving problems calls for a specialization in terms of problems rather than in terms of disciplines. This is based on the idea that development problems do not fall within the domain of any single discipline but rather should be approached from a multi-disciplinary standpoint. If an institution is to contribute to the solution of such problems, it must mirror, in terms of organization, the nature of the problems. And consequently, if a library is to be functional within such a set of organizational goals, it must also mirror the organizational nature of the institution and its philosophy, thus reflecting the nature of the problems themselves.

2. Cassava Literature

Since cassava is one of the commodity programs receiving major emphasis at CIAT, our information activities on this crop are also a concentrated effort. The problem however, as far as the literature is concerned, stems from the fact that cassava has been somewhat neglected by researchers in the past too many times, traditionally it has been considered a "backyard crop" and only sporadically has systematic research been done to improve it.

As a consequence, cassava literature is scattered throughout a wide diversity of publications and throughout many countries. In

1971, a preliminary analysis on this aspect of cassava literature was performed (1) on a sample of 162 articles published in the last four years and obtained from a search done at the National Agricultural Library, Beltsville, Maryland. Figure 1 illustrates the results of plotting the number of articles against the cumulative number of journals (in percentages).

This curve shows that approximately 50 per cent of the articles published on cassava appear in a core group of 28 per cent of the journals, and therefore, covering the remaining 50 per cent of the articles requires subscription to a great number of marginal journals. Elaborating these data further, a reference-scatter coefficient can be calculated, which is a numerical indicator of the diversity of journals in which information on a particular area appears. While the reference-scatter coefficient for all tropical and subtropical agriculture literature as calculated by Lawani (2) is 0.61, the coefficient for cassava (on the basis of the above-mentioned sample) is 0.93. It should be pointed out that a more specialized field, the petroleum literature, has a reference-scatter coefficient of 0.43 (3).

The wide scatter of the cassava literature and the need for centralizing all cassava literature as well as providing rapid access to information on any specialized aspect of cassava research and practice, made CIAT adopt a document-by-document approach in conjunction with a simple mechanized system of information handling.

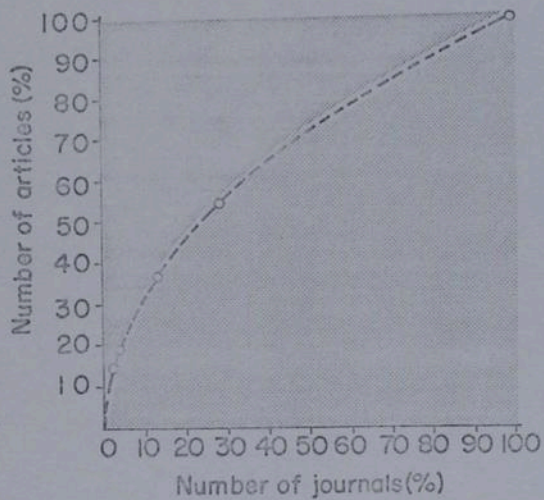


FIGURE I

3. Cassava Documentation System

With the partial support of the International Development Research Center, IDRC, of Canada, the Cassava Information Center was established as a special project under the Library and Documentation Services Program of CIAT. Since the total production of cassava documents in the world is rather small (estimated around 4,000) the Cassava Information Center aims at collecting all the literature produced on this crop. In order to accomplish this end, the CIAT Librarian travelled to several institutions in the world that were likely to have at least significant portions of the cassava literature in their holdings. Some of the institutions visited were the Royal Tropical Institute (Holland), the Tropical Products Institute (England), the Institute pour le Recherche Agronomique Tropicale, IRAT (France), and others, where copies of all their cassava references were made for future ordering of photocopies of documents. Additional contacts were made by mail and specific searches were requested from institutions such as the National Agricultural Library, Beltsville, Maryland, USA, the Instituto Brasileiro de Bibliotecologia e Documentação, IBED, Rio de Janeiro, Brazil, etc.

The final result of this initial effort to collect references was represented by 20 separate lists each containing from approximately 200 to 2,000 cassava references, on the basis of which acquisition activities began. Of the estimated 4,000 documents existing in the world on this crop, approximately 3,500 have been identified and ordered by CIAT, and nearly 3,000 already arrived.

Processing the documents after arrival is a time-consuming operation. An accession number is given to each document regardless of topic. This number will identify the document throughout its "life" in the Center. Once the complete literature citation is obtained and written according to the rules adopted by the Center, a search for an already existing abstract in any of the standard Abstract Journals is performed. If this search proves to be unsuccessful, an abstract is drawn up by our cassava specialist in the Library who is an M.S. agronomist. In some specific instances, however, a paper may require more specialized treatment, so our team of cassava specialists collaborates in making abstracts or giving technical assistance to our information science personnel.

Perhaps the most critical step in the processing of documents is that of assigning key-words or descriptors to the document since these constitute the handles, so to speak, through which documents will be located afterwards when searches on specific topics or individual interest profiles are performed. Although, key-words are obtained from the document title and text itself, many complex problems may arise in the actual use of particular words for descriptors. As an example, the word Nitrogen is most likely linked with the field of Fertilizers. However, after performing one of our first searches on this topic, we realized that Nitrogen is also quite frequent in the context of Foliar Analysis and, consequently, provisions have to be made in the system to correct for this and other types of problems.

Key-words, therefore, are not included in the system without careful consideration of their possible meanings and relations to other key-words. With the help of a thesaurus specialist, Mr. Donald Leatherdale from IDRC, a specialized cassava thesaurus was produced, which constitutes, in a way, the "official register" of terms used by the Center. In addition, this thesaurus is an invaluable tool for searching, since it includes broader terms (BT), narrower terms (NT), related terms (RT), and scope use, and use for notes (SN, USE, UF) which help to determine the specific meanings or usage of a certain term. The following example of thesauri terms may be helpful in illustrating this point.

PRICE MAINTENANCE

BT PRICES

PRICES

SN: Use for cassava products and comparative data only

BT ECONOMICS

NT PRICE MAINTENANCE

RT CASSAVA PRODUCTS

PROCESSED PRODUCTS

BT CASSAVA PRODUCTS

NT CASSAREEP

CASSAVA BEER

CASSAVA MEAL

DRIED TUBERS

FULP

TAPIOCA FLOUR

RT FERMENTED PRODUCTS

PROCESSING

SN: Processing of tubers to the manufacture (but not use)
of cassava products

NT BOILING

CENTRIFUGING

DRYING

FERMENTATION

GELATINIZATION

GRINDING
PEELING
PRESSING
PULPING
RASPING
SCREENING
SILTING
STEEPING
WASHING
RT MECHANIZATION
NUTRIENT LOSS
WATER REQUIREMENTS (PROCESSING)

Product applications
USE USES

PRODUCTION
RT ECONOMICS
FACTORIES
FORESTRY
MARKETING

Production costs
USE COSTS

PRODUCTIVITY
UF LOSS OF YIELD
YIELDS
NT ENERGY PRODUCTIVITY
STARCH PRODUCTIVITY
TUBER PRODUCTIVITY
RT WASTES

The output of the system is a card containing the bibliographic citation, the key-words and an abstract of the document. Figure 2 shows a typical abstract card.

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CIAT, Apartado Aéreo 6713, Cali, Colombia

ORE, O.L. Chemical studies on some Nigerian foodstuffs-kpokpogari (processed cassava)
Tropical Science 8(1):23-27. 1966. Engl., Sum. Engl. 6 Refs.

Cassava. Human nutrition. Kpokpogari. Nutritive value. Toxicity. RCN content.
Processing. Composition. Nigeria.

The changes that occur when cassava is processed to kpokpogari are discussed in relation to food value, mineral composition, and poisonous substances (prussic acid and oxalic acid). In the process most of the protein is lost and the product contains a correspondingly larger proportion of crude fibre. About 20 per cent of the carbohydrate is lost while the fat is reduced to nil. This leads to a lower calorific value. The ash content is doubled, corresponding to the high content of calcium. The oxalic contents of both cassava and kpokpogari are very small. From the point of view of its chemical composition, the major advantage of kpokpogari over cassava is the reduction of the prussic acid content from a lethal dose to a non-toxic level. (Author's summary)

Fig. 2

The system used for retrieval is based on the principle of optical coincidence of interior-punched cards. As described by the REMAC International Corp., manufacturers of the equipment used in our Center,

"TERMATREX is a system for storing and retrieving information.

The system, like all data and information systems, consists of items such as a research report, personnel record, correspondence, etc., which are indexed for the system, and characteristics, which are the terms used to describe these items. TERMATREX, however, is an inverted retrieval system. Where conventional systems employ a card for each item and indicate characteristics on this card, TERMATREX uses a card for each characteristic and indicates on the card every item having this characteristic.

Each TERMATREX card represents one characteristic, key word, or term. On every card there are 10,000 distinct positions. One item is assigned to each of these positions. A hole is drilled in the position assigned to an item to indicate "yes," this item has the characteristic represented by the card. The absence of a hole in the card means, "no," this item does not have this characteristic.

The information in the TERMATREX system is searched by posing a question, selecting the card or cards representing the characteristics encompassed by the question, and superimposing these cards over a light source. The holes drilled to indicate "yes" will allow light to pass through, indicating that the items represented by these positions contain material relative to the

question asked. The accession numbers of the items desired are easily determined using scale devices. The number of holes showing are rapidly counted using an automatic counting device."

4. Services provided by the Center

The Cassava Information Center at CIAT provides two types of services. One is a current awareness service by which all abstract cards are regularly distributed to subscribers.* Although the capacity for selective dissemination of information according to specific interest profiles exists within the system, this is not being done at present since it is considered that information on cassava is very scanty anyhow, and thus, cards dealing with topics not falling within the specific interest of a particular scientist may be passed on to other colleagues or institutions that would welcome this type of information.

The other service provided by the Center are retrospective searches performed on specific topics upon request. These are charged at the rate of US\$5.00 per search and always cover the entire data base at a given point in time. The user receives a set of those abstract cards dealing with the topic or combination of topics requested.

5. Projections for 1974

The Center has processed to date approximately 1,500 articles. It is expected that during 1974, an additional 2,000 to 2,500 articles will be fully processed, thus completing the major portion of past

* Current price of subscription US\$3.00 includes initial set of approximately 1,200 abstract cards.

literature. Efforts, however, will not be concentrated only on past literature but the Center will continue its present policy of giving first priority to processing current articles appearing in the literature.

Our plans for 1974 also include the publication of a bibliography in book-form of all the citations and abstracts of articles in the Cassava Information Center. Presently, all abstract cards produced at the Center are sent to IDRC in Ottawa where they are sorted by main topic in order to produce the text of the bibliography by computer. It is thought that a book-form bibliography will constitute a permanent record for cassava workers, without duplicating the flexibility of specific multi-topic searches attained by means of abstract cards.

A Directory of Cassava Workers is also being compiled. This publication will be useful in increasing communication among scientists working on this crop and, at the same time, it may be the basis for an author citation analysis to be started in the near future.

Finally, although the initiative in centralizing all cassava information and providing a rapid and versatile service to cassava scientists has been taken by IDRC and CIAT, the success of any information project depends heavily on the direct participation of those people who are the final users of the service. Consequently, we ask your personal collaboration in letting us know about new information appearing in the field in whatever form it may be. Our policy is not to be restricted only to those established forms of publication.

Internal reports, and even memoranda, frequently carry very useful and recent information that could and should be included in our service. We hope to extend and organize as far as possible, the informal network of information - sometimes called an "invisible college" - of cassava scientists so that benefits may be derived from the sharing of information by a greater number of people.

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