RECENT TRENDS IN CASSAVA BREEDING IN INDIA.

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Cassava (*Manihot esculenta Crantz.*) is rapidly emerging as a crop of considerable importance in India. More than half a million acres are now under its cultivation in Kerala state alone which accounts for about 80% of the total acreage of this crop in India. Its capacity for producing large amounts of food calories per acre, ability to adapt itself to erratic climatic conditions, resistance to locusts and several pests and diseases, easy culture, low labour requirements, low cost of production, etc. are some of its unique features which further encourage the spread of its culture to several other regions of the country. Besides, being an important item of food for a large proportion of the population in Kerala, it provides cheap, nutritive feed for livestock as well. Its tuber has innumerable industrial uses also, particularly for starch extraction (Magoon and Appan, 1966 a and b).

Though cassava has been under cultivation in India for a long time, improvement work on this crop has lagged behind. The field of activity concerning cassava breeding is thus only of recent origin and therefore, many fundamental as well as applied problems require yet to be grasped. A scheme of research on cassava was started in early years at Travancore University, Trivandrum, and the work of the scheme was greatly enlarged under the scheme of research on the improvement of cassava jointly financed by the Indian Council of Agricultural Research and the Government of Travancore-Cochin (now Kerala). The results obtained on the various aspects of the cultivation of cassava in India during 1940-57 are summarized by Koshy (1947) and Abraham (1957).

Considering the importance of the various tuber crops in the Agricultural economy of the country, the Government of India (Indian Council of Agricultural Research) recently established the Central Tuber Crops Research Institute at Trivandrum for the intensification of research on the improvement of various tuber crops, other than potato. The main function of the Institute is to undertake fundamental as well as applied work on all aspects of tuber crop improvement; some of the objectives are to evolve and formulate practical measures for increasing production of tuber crops by (i) breeding of high yielding, better quality, disease and pest resistant varieties, (ii) determination of optimum standards of culture, manuring and storage, (iii) survey, investigation and control of major diseases and pests which take a heavy toll of these crops in field and of tubers in storage, (iv) production, maintenance, multiplication and distribution of disease free, pure propagating material of improved varieties and (v) gathering fundamental data on the botany and cyto-genetics of the various tuber crops as also on certain agronomical, chemical, physiological, entomological, mycological and pathological aspects of these crops. In this article, I shall try to outline briefly some of the main items of research work at present underway on the improvement of cassava at this Institute.

A WEALTH OF MATERIAL

Genetic variability is the essence of any plant breeding programme. A germ plasm bank of the different tuber crops including wild relatives and allied material from within and outside the country has been built up.

For instance, in cassava, 960 so-called "types" have been collected from various places in India ; some have also been obtained from various countries. This entire collection is being carefully screened for several economic characteristics for purposeful utilization of this genetic variability. Studies so far made at the Institute in this regard show that there is considerable variation among the germ plasm collection with regard to physiological characters as yield of tubers, field resistance to diseases and pests, response to various levels of soil fertility, maturity period, storage behaviour of tubers, cooking quality, drought resistance and biochemical characters such as prussic acid content of tubers, starch content of tubers, etc.

Many of the cassava "types" under cultivation in Kerala and other states in India are either chance seedlings or bud mutations, selected for desirable characteristics and maintained by vegetative propagation. Varieties best suited to the requirements imposed by the local conditions are generally adopted and popularised in the various cassava growing tracts. The majority of the types have native names which generally indicate one of the striking features of the plant, like for instance, "Anakomban" meaning the tubers white and long similar to an elephant's tusk. The maturity period of the different indigenous varieties varies from 7-12 months. Varieties with lesser toxicity are generally preferred in many areas but when the crop is grown for processing the tubers into starch flour, chips, manioc meal, livestock feed, etc., and not for immediate human consumption, high yielding varieties are preferred, irrespective of bitterness.

THE NEED FOR A CLASSIFICATION

There have been divergent views regarding the classification to be adopted in this genus and to the taxonomic status to be given to the various entities, as also concerning the evolutionary relationship between them. In many instances, the delimitations of inter-, intra- and infra-specific categories in this variable group of plants lack the sharpness that a study of evolutionary inter-relationships would require (see Rogers, 1965 ; Bolhuis, 1953 ; Croizat, 1942 ; Jennings, 1959 ; Jones, 1959 and others). Cassava was classified by earlier botanists into bitter and sweet types, according to the taste of the tuberous root. Some workers assign the bitter types (those cultivars that have a high concentration of cyanogenetic glucoside in the root) to *M. utilissima* Pohl, and others refer to the sweet types (with low concentration or no cyanogenetic glucoside in the root) to a distant species, variously designated as *M. palmata, M. dulcis* or *M. aipi*. However, this differentiation has not commonly been accepted from a taxonomic standpoint, as the taste of the tuber is not regarded as a character of specific or varietal importance. Rogers (1965) has rightly emphasised the need to classify all the cultivars as one highly variable species, using the name *Manihot esculenta,* the earliest valid name proposed by Crantz (1766). Within the species several types or races, based on several morphological criteria, are recognized. Several wild forms or species are also recognized in the genus (see Rogers, 1965 ; Jennings, 1959 and others).

Attempts have been made from time to time in different parts of the world at systematically classifying the large number of so-called types or races or forms of *M. esculenta* available to the workers of the particular region on morphological criteria, geographic distribution and ecological preferences, etc. However, it must be admitted that while some notable taxonomic work has been done in this direction (see Rogers, 1957, 62, 63 and 65, Croizat, 1942, Koshy, 1947 and others) which has resulted in the recognition of species, sub-species, types, lower entities, etc., genetic and cytogenetic evidence which can additionally help in developing a more natural classification based on ancestral relationships is still far from adequate. The work in this direction has recently been taken up at this Institute. The various available types were classified to begin with on distinct vegetative characters such as colour of mature stem, young stem, emerging shoot, base of the petiole, base of the stipule, veins on the ventral surface of the leaves and growth habit, including nature of branching, etc., floral characters such as colour of perianth and disc, and tuber characters such as shape and surface texture of the tubers, colour of skin, rind and flesh, and time taken for cooking, etc. Workable keys have been prepared for identifying the distinct types on the basis of the above characters. Nine hundred and sixty cultivated so-called types collected were critically studied in the light of the above system and, it has been found that a good number of indigenous types are similar if not identical, though known by different names in different localities. Out of this collection studied, only about 100 distinct types have so far been isolated. Nevertheless, the extreme difficulty at times of identifying the clone by its observable morphological features and the changeableness of the clones when placed in different environmental conditions combine to make the system not fully satisfactory. Hence, a combined study of morphological, cytological, genetical and other aspects has been undertaken, in order to develop a more acceptable classification. It is felt that "inclusive herbarium" of the type envisaged for maize by Anderson (1951) and *Sorghum* by Magoon and his associates (Magoon, 1966; Magoon and Shambulingappa, 1962 a and b, 63; Magoon *et al*, 1961 & 64; Sadasivaiah and Magoon, 1965 and others) would be very useful in cassava as well. In these studies, besides morphological characteristics, cytological features, especially the data on the morphology of pachytene chromosomes are also included.

A comparison of the chromosome morphology and the process of meiosis in different taxa is one of the ways of arriving at an estimate of the relationship between different taxonomic entities, especially at the species and lower levels. A similar study in cassava would be most appropriate since little headway can be made in the taxonomic treatment by studies based on chromosome numbers alone, as all the cultivated indigenous types thus far studied at the Institute possess 2n = 36 chromosomes. Thus, the evaluation of comparative karyomorphological differences amongst the various types is desirable. This would necessitate the precise identification of each of the 18 chromosomes of the haploid set, preferably accompanied by the location of some marker genes on each of them. Such studies have recently been initiated.

Unfortunately, cytological studies in this group of plants, perhaps due to the lack of suitable techniques, were till recently largely confined to the determination of chromosome numbers. Critical analysis of the synaptic behaviour of chromosomes in the species or types, etc. as well as in hybrids had been greatly neglected. Chromosome homology is believed to be the property of the chromosome segments which are units of evolutionary changes. Thus, the analysis of the nature of pairing at pachytene stage in inter-specific or inter-racial hybrids or even in a population of a species provides the best chance of scanning the different regions of the bivalents for structural hybridity thereby revealing, cryptic duplications, inversions, differential segments, deletions, non-pairing segments, etc. undetectable at diakinesis and later stages. In fact, the nature of chromosome pairing particularly at the mid-pachytene stage in the hybrids studied so far has been indeed very useful in providing considerable information bearing on the presence or absence of structural changes between the chromosomes of the types. Besides, normal meiosis in some hybrids, irregularities such as the presence of minute, though cytologically detachable, structural differences like small duplications and deletions, loose pairing, differential segments, terminal and interstitial non-pairing regions, etc. have also been found in certain other hybrids. The role played by some of them in serving to restrict the homology between chromosome complements of these different taxa thereby providing an effective mechanism of genetic differentiation are being evaluated. The classification based on morphological criteria is thus supplemented by the cytological and fertility data and the various types are being lumped and re-arranged accordingly. Genetical studies have also been taken up.

A knowledge of the internal mechanisms responsible for differentiation in this group of plants is of great importance from the practical point of view also, because the breeder, has to resort to crossing, if he is to successfully incorporate some desirable genes into the commercial, cultivated forms. The procedure of incorporating the desirable genes from the related flora particularly the wild ones into the commercial forms faces various handicaps such as hybrid sterility and viability. But even when the hybrids are not sterile and are fully viable, it cannot be at once assumed that a free interchange of genes between the two species is to be expected. That this has not been realized in practice is only too well known. Stebbins, *et al* (1946) considering the limitations for such a free interchange of genes have taken recourse to the estimation of recombination index as an aid to the breeder. If the recombination index calculated on the basis of pairing and chiasma frequency at MI could be put to such use, data on pairing at pachytene stage could be all the more useful. From such a study, it should be be possible to suggest to the breeder the cross combination he should concentrate his selection upon, so that he could direct his efforts only to beneficial cross combinations among these forms.

STUDIES ON THE MECHANISM OF POLLEN ABORTION AND PROBLEMS OF NON-FLOWERING IN CASSAVA

A good number of cassava types now in cultivation rarely flower and some of them have never been known to flower. Sterility is common in crops like cassava and sweet potato which have been propagated by vegetative means for thousands of years. As a result of screening of the large number of cassava types, a varying degree of male sterility has been recorded and 35 types have been found to be completely male sterile. A comparative study of flower, microsporogenesis and development of male gametophyte in a few male fertile lines and some male sterile lines was carried out and based on extensive embryological data, the mechanism of pollen abortion in these male sterile lines has been determined. It has been found that in some male, sterile lines, degeneration of individual microspores is probably due to the failure of the separation of microspores from the tetrad which leads to the formation of empty anthers. However, in certain other male sterile lines, the pollen abortion appears to be due to the persistent nature, abnormal behaviour and development of the tapetum (Jos *et al,* 1966 and Magoon, Jose & Vasudevan, 1967). Based on cytological data, it has been suggested that meiotic abnormality is not the cause of pollen degeneration in the material studied. Attempts to study the genetics and breeding behaviour of all these male sterile lines are underway.

Attempts are also underway to study the physiology of flowering. It is now well known that environmental factors including temperature and light, growth regulators and the availability of certain metallic ions play an important role in the expression of the genes responsible for flowering (Searle, 1965). Suitable experiments have been laid out to determine the low temperature requirements and photoperiodic studies in relation to flowering in cassava. Besides, use of gibberellins (GA 3 in varying concentrations) to induce flowering in non-flowering cassava types are also being tried since the Gibberellins can replace long-day and cold treatment requirements in several plants to bring them to flowering (Lang, 1965). On the whole, it is aimed at (a) Synchronization of flowering in varieties to be crossed, (b) making non-flowering and shy flowering varieties to bloom for hybridization and (c) facilitating, if possible, crossing at any time of the year.

PRODUCTION BREEDING

Cassava yields in several parts of India are much lower than those reported from cassava producing areas in countries like Brazil, Madagascar, Java, Malaya, etc. The average yield in India is about 5 tons per acre. In India cassava has been till recently, predominantly a subsistence crop grown under sub-optimal conditions of nutrition and inferior agronomic practices by cultivators mostly in small holdings for domestic and local consumption. It is obvious that an increase in productivity can only result from the application of science and technology. In this process, improved varieties with a built-in potential for responding abundantly to such practices can obviously play a very important role as catalysts. Using better strains under intensive cultivation, high yields ranging from 20 tons to 30 tons per acre have also been reported (see Abraham, 1957 and 1956 and Magoon and Appan, 1966 a & d). Similarly, high yields of cassava have also been obtained by several progressive cultivators in Kerala.

Since cassava is nowadays emerging as a crop of considerable economic importance in India, due to its increasing utility as subsidiary food, industrial raw material and livestock feed (see Magoon and Appan, 1966 b & c) production breeding in this crop consequently must be placed on an urgent footing. Stabilizing the yields at higher and higher levels will now have to be the major problem. Greater attention will have now to be paid in developing early maturing and drought resistant varieties. In recent years, plant type has become an important breeding objective, as the importance of plant habit in the optimum utilization of solar energy has come to be well realized. The results of the preliminary manurial trials conducted at the Institute with a few indigenous commercial varieties, suggest that these do not have the capacity to respond in the optimum fashion to higher dozes of fertilizers. It is obvious, therefore, that breeding for high fertility conditions will have to be a prerequisite if any substantial improvement in the yield of cassava is to be expected within a short period. This line of work forms an important objective of the breeding programme at the Institute. In fact, some of the new selections and hybrids recently developed involving superior exotic material have been found to be particularly promising and they respond well to intensive manuring.

Breeding for the genetic improvement of yield, therefore, requires a well-balanced approach and judicious application of specialized techniques and procedures based on a clear understanding of the principles of genetics and of organic evolution. Along with breeding for yield *per se* in cassava, we have necessarily to build up genetic insurance against the virus disease, "Cassava mosaic," which has assumed serious proportions of late and reduces the yield considerably. In other words, production as well as resistance breeding, the two facets of breeding which are not mutually exclusive, (Joshi, 1963) must go hand in hand. It is only through the use of such improved varieties coupled with good, cultural practices, that cassava production can have any future in India. Consequently, varietal amelioration has received considerable attention in recent years (Abraham, 1957). The approaches to cassava breeding work at the Institute involved the use of familiar tools of introduction and assay, selection, hybridization, genome approach, mutation, etc. The main aim being to develop better varieties having desirable characters by exercising selections in indigenous as well as exotic varieties and in progenies obtained from hybridization between suitable varieties or between these varieties and their closely related wild plants. The work has been planned with specific objectives bearing in mind the requirements of farmer, consumer and industry. The cassava breeding programme is further being supported by a well organized programme of research in cognate fields such as Agronomy, Soil Science, Physiology, Biochemistry, Genetics, Cytology, Pathology and Entomology. Several experiments along these lines are underway but due to lack of space will not be referred here. However, some of the promising selections and hybrids recently developed at the Institute are worthy of special mention.

SELECTION

Considerable amount of diversity still exists in this crop in India. It is felt that vigorous selection work in natural populations, if carried out judiciously, could offer a good scope for immediate improvement of the local materials. In addition, it will also help elimination of degenerated virus infiltrated stocks and unproductive plants. A programme of selection from existing types as well as systematic testing of the available exotic material is therefore, actively under way.

Two introductions (M4, M6) from Malaya (Abraham, 1956) have been found to be high yielding. The Institute obtained seed material from several countries and the chief characteristics of some of the promising selections and hybrids developed involving certain exotic material are described at length by Magoon and Appan (1966c). For instance, two seedling selections (Accn. Nos. CTCRI-2371 and 1310) made after rigorous selections from the large collections received from Madagascar have been found to be well suited to our conditions. They have yielded up to 20 and 30 tons of tubers respectivly per acre under high fertility conditions and the plants also showed high degree of field resistance to "Cassava mosaic." Both these strains are found to be suitable for home consumption and possess an excellent cooking quality and the skin of the tubers can also be peeled off easily. They take about 8-10 months for maturity. Another high yielding seedling selection (CTCRI-300) producing medium sized stout tubers has been made at the Institute from the Brazilian stock and has been found to be particularly well suited for the industry as it possesses a starch content of about 30% on fresh weight basis. It responds well to high soil fertility, has recorded up to 25 tons yield per acre and also showed a very high degree of field resistance to "Cassava mosaic." Seedling selection (CTCRI-298) from the Malayan material has also been found to respond well to fertilization and is a heavy yielder. Tubers are creamy yellowish, very sweet and possess good cooking quality. It is, however moderately resistant to "Cassava mosaic" under field conditions. Both of them also take about 8 to 10 months for maturity. The material of the above mentioned selections is being adequately multiplied for rigorous testing on an All-India basis under different agro-climatic conditions.

INTERVARIETAL HYBRIDIZATION AND SELECTIONS FROM THE HYBRIDS

An extensive intervarietal hybridization programme having varied objectives is also underway at the Institute. Several varieties have been found to be distinctly better combiners than some other varieties. Testing of indigenous and exotic varieties of cassava for their combining ability has been a regular item of the cassava breeding programme. A large number of inter-varietal hybrids have thus been obtained and they are continuously being subjected to statistically laid out yield trials, followed by critical selections based on yield and several other criteria. Inter-varietal hybridization in cassava, if carried out on a large scale, offers great possibilities for selection of plants with desired combinations of characters. Being highly heterozygous, such crosses can be expected to give a wide segregation and allow of considerable scope for selection even in the first generation.

As a result of the large scale inter-varietal hybridization programme at the Institute, the following hybrids namely CTCRI-H. 97, CTCRI-H.50, CTCRI-H. 518 and CTCRI-H.86 have so far been selected based on yield, vigour as well as several other desirable characteristics (see also Magoon and Appan, 1966c). These hybrids in yield trials have given tuber yields of 20 to 30 tons per acre compared to 8 tons per acre even under high fertility conditions of the control. These hybrids have also shown high degree of resistance under field conditions to "Cassava mosaic." The tubers have desirable shape, are sweet in taste with low prussic acid content and possess good cooking quality. The material of these hybrids is now being adequately multiplied for further rigorous testing under different agro-climatic conditions.

EVOLVING INBRED LINES IN CASSAVA

In view of the highly heterozygous nature of the indigenous cassava types, perpetuated through years of sexual propagation, it has been suggested that selfing offers a good scope for exposing the locked up variability for selection. Koshy (1947) and Abraham (1957), on the other hand, suggested that evolving homozygous lines in cassava for the purpose of exploiting hybrid vigour offers the most promising line of work in the improvement of cassava. However, several practical difficulties (see also Abraham, 1957) such as variable time of flowering and difference in time of maturing of male and female flowers in a plant, rapid loss of yield, poor flowering and vigour, pollen sterility, etc., even after two to three generations of selfing, etc., are being faced and no less than 6 generations of selfing may be rquired to obtain good homozygous lines in the material under study.

Two points need to be considered in this connection. First, it is not clear whether such a procedure is essential for exploiting hybrid vigour in this crop. For, once a high performing genotype or clone has been established, thanks to the possibility of vegetative reproduction, it can be maintained without difficulty and also multiplied rapidly. Hence, inbreeding which is essentially practised to obtain fixed, repeatable genotypes in seed reproduced taxa may not be an essential step in exploiting hybrid vigour in cassava. Secondly, the great danger of distributing a single genotype over wide areas should not be lost sight of.

It is obvious therefore, that it would not be profitable to employ in cassava the most popular method of corn improvement, viz., producing hybrids of the best combining inbreds, because in maize, which is seed propagated, the objective is a uniform superior population, while in cassava, however, it is the superior individual, which once selected, can be vegetatively multiplied into an agronomically uniform population of any desired size. Further, neither the inbreds by themselves can be expected to satisfy the commercial requirements of the crop. Besides, the inter-varietal hybridization programme between selected varieties of known combining ability which has thus far produced very satisfactory results as described in the preceding section, efforts are also being made to cross one generation selfed lines of selected types with the best pollinator. Production of multiclonal hybrid varieties is also being considered.

INTER-SPECIFIC HYBRIDIZATION

Inter-specific hybridization and genome analysis carried out on different crops have opened up new avenues of improvement of crop plants and have successfully contributed to the development of radically new and better types. However, as compared to other crops, cassava breeders have not yet scratched the surface in utilizing the genetic variability occurring within the species in nature. Added to the genes in the cultivated types are the vast array of genes in related "species" which possess reservoirs of unexplored genetic characters, incorporation of which into the cultivated varieties would appear to be of prime importance in any modern cassava breeding programme. The transfer of characters from one taxa to another is not only of great, potential, practical importance, but is of considerable genetic interest as well. It is therefore, important to extend the limits of transfer as far as possible. In fact, modern advances in cytogenetics, embryo culture, polyploidy, use of bridging species, alien chromosome and gene substitution and other techniques are expanding the range of species from which desired genes can be borrowed so as to make the commercial varieties more suitable to current human needs.

All species of the large genus *Manihot* are confined as wild plants to the American tropics ; no native species are found in the old world (Rogers, 1965). There are certain "species" group in the genus, the progress of speciation among forms of the same group is comparatively weak, so that related species are connected by inter-grades (see Rogers, 1965, Bolhuis, 1949 and 1953), Croizat, 1942 and Jennings, 1959). Very few "species" have been used so far in the breeding programmes and this may probably be due to the non-availability of extensive specific collections at various research centres. However, some useful work relating to inter-specific crossing for breeding improved cassava varieties have been reported. For instance, in Java, Koch (for detailed reference, see Jennings, 1959) reported successful crossing of cassava with *Manihot glaziovii* (Ceara rubber) and *M. dichotoma* (Jaquie *Manicoba* rubber) ; in East Africa, Nichols (1947) and Jennings (1957) described the use of these species together with the tree like species, *M. catingea* and two herbaceous species *M. saxicola* and *M. melanobasis* ; *M. glaziovii* has also been utilized extensively in the cassava breeding reported from Madagascar (Cours, 1951). By several generations of back crosses of these hybrids to cassava, new types of cassava, highly resistant to virus diseases, were evolved which led to greatly increased yields (see Ann. Rep. E. African Inst.

at Amani ; Nichols, 1947 and Jennings, 1957 & 1963).

Crosses between *Manihot melanobasis* and cassava were very fertile and the fertility was maintained in the hybrids (Jennings, 1959). The first and subsequent generations of these crosses were very high yielding. The species has been found to be a very valuable source of new genes for cassava improvement. He felt that in view of the readiness with which the two species inter-cross, it is doubtful whether their separation as distinct species is justified. Bolhuis (1953) arrived at the same conclusion for *M. saxicola* which also inter-cross freely. In India, Koshy (1947) and Abraham (1957) also reported successful crosses between cassava and Ceara rubber followed by several generations of back crosses with cassava. Chemical analysis of tubers is underway, before they can be released for general cultivation. Recently, Magoon, Jos and Appan (1967) at the Institute have also successfully made this cross using cassava as the female parent and *M. glaziovii* as the male parent. Pachytene pairing was found to be apparently normal and complete along the entire length of the bivalents in the F1 hybrid, with the exception of one bivalent which showed very small terminal as well as interstitial non-pairing segments. One bivalent also showed loose pairing in some regions. Eighteen II's were usually present at MI, though occasionally two to three bivalents showed the tendency to separate precociously at this stage. The average chiasma frequency at MI (mean of 20 cells) was found to be 17.3 per cell. About 15% of the microsporocytes analyzed at AI showed 1 to 3 laggards. A few lagging chromosomes were also noted in about 20% of the cells at AII. One to two micronuclei were occasionally present at the sporad stage. The F1 hybrid showed a very high degree of pollen sterility. The female fertility was moderate. A backcross programme with the cassava parent has also been taken up.

It may thus be seen that considerable scope exists in intensifying the work of inter-specific hybridization in the genus *Manihot,* as large numbers of "species" have been reported in the genus (see Jennings, 1959), but however, as stated above, only a few species have so far been used in the breeding programmes. In fact, very little is known to the breeder concerning the remaining wild forms. In view of the growing importance of the crop in the tropics, cassava breeders will in the near future be faced with increasing demands for high yielding, disease and pest resistant types having several other desirable values and storage qualities and qualities satisfying the demands of the industry. This can be greatly made possible only through intensive collections and assemblage of the entire germ plasm of this genus from areas of origin and centres of diversity and assessing their performance in the various suitable centres of the world dealing with the improvement of this economically important crop. There is an urgent need for international co-operation for collection, maintenance, multiplication and proper evaluation of this vast diversity for effective screening and full exploitation of sources of this genetic diversity in improvement work in this crop.

RESISTANCE BREEDING

The increasing importance of diseases has stimulated considerable interest in resistance breeding. In fact, this is one way of stepping up production by removing the "bottleneck" genes (Joshi, 1963) which tend to limit the expression of the inherent yielding ability of the plant under the influence of unfavourable environmental conditions including diseases and pests. Amongst the diseases infecting the crop, "Cassava mosaic" is a factor seriously limiting production of cassava in India. Though, considerable research work on different aspects of "cassava mosaic" and brown streak have been done in Nigeria, East Africa, Madagascar, Brazil, etc. (see Nichols, 1947 ; Jennings, 1957, 1960 a and b ; Chant, 1958 ; Silva, 1962 ; Jameson, 1964 and others), little attention, has, however, been paid in India to the problem of breeding varieties resistant to "Cassava mosaic" diseases. Intensification of research on all aspects of this virus disease is, therefore, an urgent necessity in view of the ravages that virus diseases cause.

This disease is caused possibly by a complex of viruses. The virus disease syndrome of cassava plants is extremely varied. However, the chief symptom of the "Cassava mosaic" disease is the mottling of the leaves due to degeneration of chlorophyll. In severe cases the leaves become small, curl and get distorted. The leaf blade gets reduced to a narrow strip along the veins ; the internodes are shortened. The plants remain markedly stunted and form few and small tubers. The "cassava Mosaic" is carried by white flies of the genus *Bemesia,* but is also distributed by planting infected stem cuttings.

Adequate control of virus disease in general presents considerable difficulties. Rogueing the diseased plants wherever possible and practical must be practised but this method does not ensure complete success. Similarly, eradication of vectors of the disease is not considered practical. Therefore, the economical and practical method of control is the development of resistant varieties. An essential prerequisite for breeding for disease resistance is the availability of a suitable source of resistance. The desired resistance may be found within the cultivated species itself or only in the related wild species. For obvious reasons, the resistance occurring within the cultivated species is more desirable since it can be more easily transferred to an otherwise superior but susceptible variety. Further, for successful planning of the resistance breeding programme, an appraisal of the mechanisms of resistance and its genetic basis is quite essential. In fact, it is very desirable to secure a reliable picture of genetic mechanism of resistance at as early a stage of the programme as is possible, so that the breeding programme could be appropriately oriented to suit the situation. Routine testing of genetic stocks under natural conditions may lead to evolution of varieties with assured degree of resistance. Considering the economic importance of the disease and in view of the fact that very little attention has been paid in the past to this disease, a comprehensive virus unit has recently been established in the Institute to deal with the "Cassava mosaic" disease and other virus diseases of some other tuber crops. The programme of work on breeding virus resistant, cassava varieties, in general includes :

(1) A survey of the incidence of "Cassava mosaic" in different cassava varieties in various agro-climatic locations.

(2) A study of symptomatology and of the estimate of the losses in yields.

(3) Differentiation of resistant and susceptible genotypes and utilization of the resistant stocks in hybridization programmes.

(4) A study on the biology of the viruses, their modes of transmission, pathological physiology of infected plants and the genetics of the disease resistance.

As already stated, the value of germ plasm collection and the proper way of systematically screening and successfully utilizing it in an active programme of production as well as resistance breeding cannot be over emphasized. Information on disease resistance, both in the indigenous as well as available exotic types, is now being continuously gathered. The Institute is also further exploring the possibilities of collecting superior germ plasm of cassava from several parts of the world so as to screen and locate more and more sources of resistance with a view to increasing the pool of resistance genus for successful breeding of resistant varieties.

The exotic material already available at the Institute is being critically studied from two angles, (i) determining if any, of these exotic varieties could be directly used for cultivation, (ii) effective utilization of these material as breeding stocks. In fact, some of the new selections and hybrid combinations of cassava, viz. CTCRI-300, CICRI-1310, CTCRI-H.50, CTCRI-H.86 CTCRI-H.97 recently developed at the Institute have shown a high degree of field resistance to "Cassava mosaic" and have also proved to be heavy yielders. They are now being further subjected to extensive laboratory tests to determine the stability of the resistance to virus infection and the stability of agronomic qualities.

GENOME APPROACH TO CASSAVA IMPROVEMENT

A considerable proportion of the forms in various tuber crops with which the plant breeder deals are in fact polyploids which undoubtedly pose many difficulties in their improvement. Boiteau (1941) has reported the natural occurrence of a polyploid series of cassava in Madagascar. Jennings (1963), taking into consideration the chromosome numbers of other genera in the *Euphorbiaceae* together with evidence from studies of meiosis in the species itself, suggests that cassava is an allopolyploid. The polyploids, whether autopolyploid or amphipolyploid, possess highly buffered genetic systems.

The buffering is expressed in polysomic inheritance in autopolyploids and in intergenomic episatic effects in amphipolyploids with the result that unless a polyploid is reduced to its basic genomes, it may not be easy, unlike in diploids, to treat the problems of intra- and inter-genomic repatterning. What can be achieved when the requisite basic knowledge is available, is strikingly illustrated by the interesting work with wheat where such genome approach has paid considerable dividends. With a view to evaluate this approach in the improvement of cassava, in addition to analysis of interspecific hybrids, a programme of artificial induction of haploidy (see review by Magoon and Khanna, 1963 for terminology classification and utility of haploids) in some of these crops has recently been initiated at the Institute using several techniques including among others, (i) delayed pollination, (ii) use of abortive pollen, (iii) distant hybridization, (iv) high and low temperature, (v) irradiation and (vi) treatment with various chemicals. There is no doubt, however, that their use can be practical only in the crops where they can be produced and screened in fairly large numbers as has been found in commercial potato by Hougas and Peloquin and their collaborators at the University of Wisconsin, U.S.A. (see for review, Hougas and Peloquin, 1958). Recently, analytic breeding, which involves, (a) reduction of a polyploid to its diploid components, (b) intensive breeding and selection at the diploid sporophytic level and (c) resynthesis and testing of the polyploid form, has been critically discussed by Chase (1963) outlining the advantages, operative steps and assumptions involved in this radical approach to the improvement of several polyploid plant varieties. The chief objective is to reverse the evolutionary pathway, from polyploidy back to diploidy, with a view to intensify selective breeding and to set the stage for retracing the evolutionary sequence from ancestral diploidy to polyploidy with genomes moulded more closely to current human needs (Chase, 1964). It is thus apparent from the recent work on potato (see for review, Magoon *et al,* 1962) that such an approach particularly in vegetatively propagated crops in which little or no seed production is required affords good possibilities of improvement and re-fashioning the polyploids into forms more suitable to our present needs.

PRODUCTION OF CHROMOSOMAL RACES

Another line of approach in the cassava improvement programme, besides hybridzation and analytic methods of breeding, which warrants investigation is the production of colchiploids as well as "triploids." Graner (1941) and Abraham *et al* (1964) described colchicine induced tetraploids of cassava. "Triploids" ($3n = 54$) were also obtained by the latter authors by crossing induced tetraploids with some of the cultivated cassava varieties and they were found to be superior to colchiploids in yield and sometimes outyielded "diploids" ($2n = 36$) also. The relative merits of "triploid" ($3n = 54$) cassavas need study. Triploids have been shown as superior cultivars in several crop plants. Marks (1966) argues that their survival as cultivars means that they possess certain selective advantages as cultivars, advantages often concomitant with triploidy *per se*. Triploid cultivated bananas have been found to be better in productivity vigour, sterility and variability (Simmonds, 1962). In sugar beet and American Apples also, triploids are superior (Allard, 1960). Kihara (1951) reports that intra- and inter-varietal triploid watermelons are much superior to either diploids or tetraploids in yield per unit area. Similarly, Larsen (1954) recommends breeding triploids in Alnus, Betual and Populus because of their superior growth rates and vigour. Marks (1966) suggests that relative merits of triploid cultivated potatoes warrant investigation.

As stated earlier, all cultivated indigenous types of cassava thus far screened possess 2n = 36 chromosomes. Therefore, with a view to test the yielding potentialities and adaptability of colchiploids, tetraploidy has been successfully induced through colchicine treatment in a few agronomically superior varieties of cassava. The colchiploids possess 72 chromosomes and the material is now being adequately multiplied for large scale yields trials. These induced tetraploids are also being crossed with some of the selected cultivated $2n = 36$ types so as to produce "triploids" (3n = 54). A few seeds have already been obtained and will be sown shortly.

MUTATION BREEDING

The use of radiation to produce genetic variants is a useful tool of potential value in agriculture, capable of being employed as an adjunct to conventional procedures. Besides, other uses, this technique has been found particularly useful in rectifying specific defects in otherwise desirable varieties. Other situations in which radiation breeding might be a method of choice are where tight linkages have to be broken or in the introduction of specific characters especially into vegetatively reproduced plants where the extreme heterozygozity is likely to make recombination breeding difficult (Mackey, 1956 and Pal, 1965). Using a wide variety of mutagens, a mutation breeding programme in cassava has been taken up recently at the Institute with the hope that once suitable treatments and handling techniques are refined in this material, this method could also be extensively utilized in future cassava breeding research. The polyploid condition of cassava

(Jennings, 1963) may not be of any handicap in mutation work since recent results with polyploid crop plants (Swaminathan, 1957) suggest that polyploids, because of their greater variability after mutagenic treatment and also because of their greater buffering or homeostatic capacity, might turn out to be particularly suitable material for such methods. The radiation programme has been taken up with the following three objectives in view :

(1) *Induction of mutations in respect of specific characters:*

It is felt that to begin with irradiation of popular and otherwise desirable cassava varieties suffering from any serious defect or defects, like late maturity, non-flowering habit, disease or pest susceptibility, lodging, etc. may be taken up to secure mutants free from these defects and thus rehabilitate the varieties for commerical cultivation. A fairly large amount of material of certain desirable commercial varieties (seeds, varying sizes of stem bits, etc.) of cassava were irradiated with one physical mutagen, viz. gamma rays taking advantage of the facilities of Cobalt 60 source and dozimetry cell at the Indian Agricultural Research Institute, New Delhi. Since the optimum doze of irradiation had not been previously determined, a wide range of treatment has been tried in each case. The material thus treated has already been planted in the field along with the control and is being screened. There appears to be a differential varietal response to the treatments given. L.D. 50 for each variety is being established. Further, treatments with other two physical mutagens viz. X-rays and neutrons are also being taken up. Since it is possible to successfully germinate even a single bud in cassava (the technique of single bud culture has been standardized and also utilized to best advantage among other uses for ensuring rapid multiplication of the cassava material) the chemical mutagens also offer good possibility for maximizing the mutation frequency and the work in this direction has also been taken up.

(2) Induction of haploidy for utility in several basic fundamental as well as applied problems.

Because of the great theoretical and applied potentialities of "haploids", a number of methods including, the use of radiations (pollinations with different dozes of X-ray or gamma rays radiated pollen in hybridization programme in selected varieties having suitable genetic markers with the hope of providing stimulus to the egg to develop parthenogenetically) is being tried for the artificial production of "haploids" in cassava.

(3) To study the spectrum and nature of mutations induced by different mutagens in different genotypes.

Since the success in mutation breeding would depend on the frequency and variety of mutations induced, the treated material will also be studied in regard to types of mutations induced by different mutagens and treatment methods.

SUMMARY

The range of available genetic variability in the crop is presented. The opportunities of further improvement of cassava, through efficient exploitation of the germ plasm reserves available, seem exceedingly great. The need for conducting combined study of morphological, cytological and genetical aspects in arriving at a more natural, botanical classification based on ancestral relationships has been stressed since such knowledge is indispensable to the breeder and also finds important applications in certain other fields. Problems and approaches of current interest in relation to production and resistance breeding have been discussed. The chief characteristics of the selections and high yielding hybrids recently developed at the Institute are briefly described. Work relating to interspecific hybridization, production of chromosomal races and mutation breeding and their implications in the cassava improvement are briefly reviewed. The genome approach to cassava improvement has been discussed. It is suggested that the separation of the intragenomic and intergenomic phases of plant improvement offers the cassava breeder considerable scope for better genetic control than presently obtained.

REFERENCES

1. Abraham, A. (1956). Tapioca cultivation in India. **Farm Bull.** 17 (I.C.A.R.).
2. ———— (1957). Breeding of tuber crops. **Ind. J. Genet.** 17 : 212—217.
3. Abraham, A., Panicker, P.K.S. and Mathew, P.M. (1964). Polyploidy in relation to breeding in tuber crops. **J. Ind. Bot. Soc.** KLIII(2): 269—282.
4. Allard, R.W. (1960). Principles of Plant Breeding. John Wiley & Sons, New York.
5. Anderson, E. (1951). Inclusive herbaria. **Ind. J. Genet.** 11 : 1—4.
6. Boiteau, P. (1941). Nouvelles observations cytologique surle manioc cultive. **Chron. Bot.** 6 : 388.
7. Bolhuis, G.G. (1949). Hybridzation in cassava. **Landbouw,** 21 : 535—58.
8. ———— (1953). A survey of some attempts to breed cassava varieties with a high content of proteins in the roots. **Euphytica 2** : 107—112.
9. Chant, S.R. (1958). Studies on the transmission of cassava mosaic virus by Bemesia spp. (Aleyrodidae). Ann. App. Biol. 462 : 210—215.
10. Chase, S.S. (1963). Analytic breeding on **Solanum tuberosum** L. **Can Genet. Cytol.** 5 : 359—363.
11. ———— (1964). Analytic breeding of Amphipolyploid plant varieties. Crop. Sci., 4 : 334—337.
12. Cours, G. (1951). Le manioc a Madagascar, Memoires de L'Institut Scientifique de Madagascar. **Serie B,** 3 : 203—400.
13. Croizat, L. (1942). A study of **Manihot** in North America. **J. Arnold Arboretum,** 23 : 216—225.
14. Graner, E.A. (1941). Polyploid cassava induced by colchicine treatment. **J. Heredity,** 32 : 281—88.
15. Hougas, R.W. and Peloquin, S.J. (1958). The potential of potato haploids in breeding and genetic research. **Amer. Potato J.**, 35 (19): 701—707.
16. Jameson, J.D. (1964). Cassava mosaic in Uganda. **E. Afr. Agri. Forest J.,** 29(3) : 208—213.
17. Jennings, D.L. (1957). Further studies in breeding cassava for virus resistance. **E. Afr. Agri J.,** 22 : 213—219.
18. ———— (1959). **Manihot melanobasis** MULL. Agr. A useful parent for cassava breeding. **Euphytica** 8 : 157—162.
19. ———— (1960a). Observations on virus diseases of cassava in resistant and susceptible varieties I. Mosaic disease. **Emp. J. Exp. Agri.,** 28 : 23—24.
20. ———— (1960b). Observations on virus diseases of cassava in resistant and susceptible varieties. II. Brown Streak disease. **Emp. J. Exp. Agri.,** 28 : 261—270.
21. ———— (1963). Variations in pollen and ovule fertility in varieties of cassava and the effect of interspecific crossing on fertility. **Euphytica,** 12 : 69—76.
22. Jones, W.O. (1959). Manioc in Africa. Stanford University Press, California.
23. Jos, J.S., Magoon, M.L., Sadasivaiah, R.S. and Appan, S.G. (1966) Studies on sterility in cassava I — Mechanism of pollen abortion in some male sterile lines. **Ind. J. Hort.** (in press).
24. Joshi, A.B. (1963). Producing breeding. **Ind. J. Genet.,** 23 : 109—16.
25. Kihara, H. (1951). Triploid watermelons. **Proc. Amer. Soc. Hort. Sci.,** 58, 217—230.

26. Koshy, T.K. (1947). The tapioca plant and methods for evolving improved strains for cultivation. **Proc. Ind. Acad. Sci.,** 26(2): 32—59.

27. Lang, A.. (1965). Physiology of flowering. **Encylopedia Plant Physiol. Ed.** W.H. Ruhland.

28. Larsen, C.S. (1954). Genetics in Silviculture. Oliver & Boyd. Edinburgh.

29. Mackey, J. (1956). Mutation breeding in Europe. **Brook Symp. (Genetics Plant Breeding)** 9 : 141—156.

30. Magoon, M.L. (1966). The role of some internal mechanisms in species differentiation. **Plant Breed. Res., I.A.R.I.** (Commemoration Vol.) 4(1 & 2) 68—78.

31. Magoon, M.L. and Appan, S.G. (1966a). Cassava — A food for the Millions. Ind. Eng. 16(1): 12—13.

32. ——— and ——— (1966b). The industrial utility of cassava. **Kerala Labour & Ind. Rev.** 4(3): 1—6.

33. ——— and ——— (1966c). Promising new selections in cassava. Vistas in crop yields. **I.C.A.R. Year Book** (in press).

34. ——— and ——— (1966d). Cassava cultivation in India. **Farm Bull., I.C.A.R.** (in press).

35. ———, J.S. Jose, and S.G. Appan, (1967). Cytomorphology of the interspecific hybrid between cassava and ceara rubber (in press).

36. ——— ——— and K.N. Vasudevan, (1967). Male sterile cassava (in press).

37. ———, and K.R. Khanna, (1963). Haploids. **Caryologia,** 16(1) : 191—235.

38. ———, P.L. Manchanda, and M.S. Ramanna, (1964). Cytological and morphological students in the **genus Sorghum. Cytologia,** 29 : 42—60.

39. ———, S. Ramanujam, and D. C. Cooper, (1962). Cytogenetical, studies in relation to the origin and differentiation of species in the **genus Solanum L. Caryologia,** 15(1): 151—252.

40. ——— and K.G. Shambulingappa, (196a). Cytological and morphological studies of some interspecific hybrids in **Eu-Sorghums. Z. Indukt. Abstamm. u. Vereb-Lehre,** 93 : 14—24.

41. ——— and ——— (1962b). Cytomorphological studies of some species and species hybrids in the **genus Sorghum.** Der Zuchter, 32 : 317—24.

42. ——— and ——— (1962b). Cytomorphological studies of some species and species hybrids in the **genus Sorghum. Der Zuchter,** 32 : 317—24.

43. ——— and ——— (1963). Cytomorphological studies of some species and hybrids in the **Eu-Sorghums.** Chromosoma (Berl.), 14: 572-588.

44. ——— ——— M.S. Ramana, (1961) Chromosome morphology and meiosis in some **Eu-Sorghums. Cytologia, 26** : 236-252.

45. Marks, C.E., (1966). The enigma of triploid potatoes. **Euphytica** 15 : 285-290.

46. Pal, B.P. (1965). Recent advances in plant breeding procedures A chapter in Madras Agri. J. (Golden Jubilee No.)

47. Rogers, D.J. (1957). Intraspecific categories of M. esculenta. Sci. 126 : 1234-35.

48. ——— (1962). Origin and development of **Manihot esculenta** and allied species. Amer. J. Bot., 49(6): Part 2.

49. ——— (1963). Studies of **Manihot esculenta** Crantz. (Cassava) and related species. **Bull. Torr. Bot. Club.** 90(1); 43-54.

50. ——— (1965). Some botanical and ethnological considerations of **Manihot esculenta. Econ. Bot.** 19(4): 369-77.

51. Sadasivaiah, R.S. and M.L. Magoon, (1965). Cytological and morphological studies of some species and species hybrids in the genus **Sorghum. Can. J. Genet. Cytol.,** 7 : 591-608.

Searle, N.E. (1965). Physiology of flowering. Ann. Rev. **Plant Physiol.** 16: 97-118.

Silva, D.M. (1962). Obtaining antiserum against Cassava Mosaic virus. **Brogantia,** 21 : XCIX-CII.

Simmonds, N.W. (1962). The evolution of the banana. **Longmans** Green, London.

Stebbins, G. L., J. I. Valencia, and R. M. Valencia. (1946). Artificial and natural hybrids in gramineae. tribe HordeaeI. Elymus, Sitanion and Agropyron. **Amer. J. Bot.,** 33 : 338-351.

Swaninathan, M.S. (1957). Polvploidy and sensitivity to mutagens. **Ind. J. Genet.,** 17(2): 296-304.