Cassava Breeding

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ABSTRACT

The main factors concerned with cassava breeding are described, such as origin and domestication, botanic classification and relationship with other species, reproduction mode and floral biology, factors that influence flowering, factors that affect hybridization and seed production, genetics and cytogenetics, qualitative trait heredity, selection criteria for yield, hybridization techniques, general and specific breeding objectives, breeding methods, diffusion of new varieties, current state of breeding, main results and impacts, the future of breeding and cultivars recommended in Brazil. The main results obtained at the national and international level in the areas of germplasm and cassava genetic improvement are presented. A list is included with the description of the cultivars for the Northern, Northeastern, Southeastern, Central-Western and Southern regions of Brazil.

KEY WORDS: *Manihot esculenta,* germplasm, domestication, cytogenetics, breeding methods, varieties.

IMPORTANCE AND EVOLUTION OF CASSAVA BREEDING

First grown by the Indians in South America, the Cassava (*Manihot esculenta* Crantz) has been cultivated in Brazil (Schaall et al., 1994) for more than five hundred years. It was later introduced in Africa and Asia where it became the basis for subsistence for the needy populations living in the poorest areas of these continents.

This species presents wide genetic diversity which is concentrated mainly in Latin America and in the Caribbean. Approximately 8,500 cassava accessions are kept in the various collections worldwide, out of which 7,500 are found in South America (Costa & Morrales, 1994). In Brazil 4,132 accessions have been collected and maintained in germplasm banks throughout the country (Fukuda, 2000). This wide genetic diversity results from the easy cross - pollination of the species, its high heterozygosity and its abrupt fruit dehiscence. It is usually represented by native varieties selected naturally or by farmers (Fukuda, 1996).

Cassava is cultivated throughout Brazil from the Amazon Region to Rio Grande do Sul, under the most different climate, soil and management systems. Thus there is a demand for different types of cultivars adapted to these environment conditions and uses. The use depends on the region; generally the whole cassava plant is used either in human or animal nutrition. The cultivars present certain specific characteristics for each use.

Progress in crop breeding for adaptation and quality improvement has taken place over many centuries of selection in the Americas and, in the last 300 years, in Africa and Asia, resulting in a wide genetic diversity (Bonierbale et al., 1995). One of the first reports on cassava variety assessment and selection was published in Bahia state, Brazil, in 1899 (Zehntner, 1919). But it was during the twentieth century that the national institutions began to organize themselves for the genetic breeding of this crop. An active cassava breeding program began in Brazil (Normanha, 1970) and in some African colonies in the mid twentieth century. In the latter, the presence of a strong biological component, the African Mosaic Virus, led researchers in West Africa to assess and use the genetic diversity from some wild species of the *Manihot* genus in their breeding programs. The germplasm derived from these programs was for many years the main source of resistance used to control the African Mosaic Virus (Jennings, 1976).

With the advent of International Research Centers in the 1960s there was a new incentive for germplasm collection, characterization and development of new cassava cultivars. The studies at the International Tropical Agriculture Center (CIAT) and the International Institute of Tropical Agriculture (IITA), in partnership with the National Centers (Dixon et

al., 1994; Porto et al., 1994), led to the regional and global development as well as exchange of cassava germplasm collections and to the integration with other breeding programs. The successful release and adoption of bred cassava varieties had a major impact in Asia (Thailand, Indonesia and Vietnam), where the development of cassava cultivation has been stimulated by a dynamic processing sector (Kawano et al., 1998).

Considerable success in developing new sources of African Mosaic Virus resistance and cultivars with great yield potential has been achieved by the International Institute of Tropical Agriculture (IITA) and by partnership programs in Africa (Hahn, 1984). The release and adoption of new cassava varieties in Latin America have increased recently with the promotion of cassava for animal nutrition and starch production (Second and Inglesias, 2000) and with the implementation of methodologies which include farmer participation in cassava breeding (Fukuda and Saad, 2001).

Cassava breeding is developed in different stages such as assessment of the 'landrace´ varieties, regional and global germplasm collection and exchange, clone recombination and collection and the use of wild species to broaden the genetic base. Biotechnology has been used since the 1980s to facilitate and increase efficiency in cassava breeding .

Genetic improvement studies on cassava cultivation in Brazil started in the mid twentieth century (Normanha, 1970) and were intensified in the 1940s by regional research institutions that sought to meet regional demand (Fukuda and Porto, 1991; Fukuda, 1992). Basically they concentrated on the introduction and assessment of the available germplasm (Fukuda, 1996).

In Southeast Brazil, the first cassava genetic improvement research was carried out by the Campinas Agronomic Institute (IAC) in 1940, using recombination among the varieties by controlled crosses among heterozygous parents and selections during successive generations of plant multiplication (Normanha 1971; Pereira and Lorenzi, 1975). The program was expanded in 1969 with the significant increase in new clone generation. Along with the crossing studies, the IAC carried out a systematic collection of cassava germplasm in São Paulo State.

Cassava breeding research began in Minas Gerais in the 1950s at the Central-Western Institute of Agricultural Research (IPEACO) with the collection and selection of varieties adapted to the state.

In the State of Rio de Janeiro, the Central-Southern Agriculture Research Institute (IPEACS) began a cassava breeding research that consisted of germplasm introduction and assessment.

In Northern Brazil, the Northern Institute of Agricultural Research (IPEAN) started the first cassava breeding research in 1947, when the first controlled crosses and self-pollinations were made and regional cultivars were collected.

Cassava breeding began in Northeast Brazil in 1952 at the Eastern Institute for Agricultural Research (IPEAL) in Bahia to collect and assess regional varieties and open pollination. In 1969 the Agronomy School at the Federal University of Bahia (EAUFBA) in Cruz das Almas-BA launched a cassava genetic improvement program for the Northeast by setting up a germplasm bank and creating and assessing thousands of hybrids (Conceição, 1979).

In the South cassava breeding studies began in 1942 by the Rio Grande do Sul state Secretary of Agriculture with the setting up and assessment of a germplasm bank with 500 accessions and the creation of new clones by recombination. Many of the varieties recommended in this period are still used by cassava producers.

In 1976, Embrapa, in partnership with the State Research Units and universities, began to develop and coordinate cassava genetic improvement projects to cater to the different ecosystems in Brazil.

Few research institutions in Brazil have generated and selected new clones by recombination. However, there are important studies on cassava for the Cerrados by Embrapa Cerrados, for São Paulo State by the Campinas Agronomic Institute (IAC) and for different ecosystems and forms of use, carried out by the Embrapa Cassava and Fruit Crop.

This research resulted in a wider cassava genetic base for the Brazilian germplasm banks, where new clones, resistant to the main diseases and pests, and with high root yield potential and adapted to the different ecosystems, were generated and identified.

There have been significant gains in recent years from the intensification of recombination studies by crosses with the release of several hybrids resistant to diseases and pests, high root yield potential and acceptance by cassava farmers.

This study was carried out to describe the methods of genetic improvement used in cassava, the results obtained and the future perspectives in cassava breeding.

ORIGIN AND DOMESTICATION

In the last ten years, considerable knowledge on the botanic aspect, geographic origin and domestication centers of cassava cultivation has been developed (Allem, 1994a; Allem, 1999). Allem (1987) proposed that cassava had been domesticated from wild species and suggested that *Manihot esculenta* Crantz ssp. *flabellifolia* (Pohl) and *Manihot esculenta* Crantz ssp. *Peruviana* (Mueller Agroviensis) were the possible ancestors of cassava.

Recently Allem (1999) considered *M. pruinosa* as another possible cassava ancestor, based on cross data and molecular markers generated by Second et al. (1997).

According to Allem (1994b), these species are found in tropical and marginal forests, Cerrados and in the Central Western Regions of Brazil, while *M. pruinosa* is concentrated in the states of Goiás and Mato Grosso, which may be possible centers of origin for cassava. He also reported that *M. pruinosa* presented two branching habits depending on the environment in which it was found: erect in uncultivated regions and creeping in cultivated areas (1999). Phillogenetic Analyses of the *Manihot* genus carried out by Schaal et al. (1994) based on molecular markers indicated that cassava originated in South America.

Cassava characterization studies that included AFLP (Roa et al., 1997) and microsatellites (Roa et al., 2000) on four cassava species from South America (wild *M. esculenta, M. tristis, M. carthaginensis* and *M. brachyloba*), in addition to *M. aesculifolia*, confirmed Allem´s hypothesis (1994a) that cassava is directly related to wild *M. esculenta.* Only a small portion of the genome differs between the wild and cultivated *M. esculenta*. Similarly, Olsen and Shaal (1999) quoted by Carvalho et al. (2000) proved that *M. esculenta* ssp. *flabellifolia* is the ancestor of the cultivated species.

Cassava is a cultigen species of American origin (Allem and Goerdet, 1991). It is not found in the wild form and apparently developed as a cultivated species by natural selection and human action (Hershey and Amaya, 1982). It was domesticated by pre-Colombian peoples for root production from wild species of the *M. esculenta* genus. Archeological evidence from Colombia and Venezuela indicates that cassava has been cultivated in these regions for 3,000 to 7,000 years (Renovoize, 1973; Reichel-Dolmantoff, 1957).

Botanic classification

Within the botanical hierarchical classification system, cassava belongs to the Dicotiledonea class, the Euphorbiaceae family, the Manihoteae tribe, the *Manihot* genus and the *Manihot esculenta* Crantz species.

About 98 species have already been identified in the *Manihot* genus (Rogers and Appan, 1973). *M. esculenta* is the only species of this genus cultivated commercially for edible root production and has the following synonyms: *M. utilissima, M. edulis* and *M. aipi*. It is also known in Latin America as cassava (manioc in Brazil) and yucca (in other Spanish-speaking countries), as cassava, manioc, manioca and tapioca in the North American continent and in European countries and as suahili, mhogo and omowgo in Asian and African countries (Dominguez et al., 1982).

In the western hemisphere farmers usually classify the cassava varieties as sweet or bitter, according to the cyanic acid content of the roots, and there is no relationship with the taxonomic classification (Rogers and Appan, 1973). The species of the *Manihot* genus present wide genetic variety for traits of agronomic interest and promising perspective for introgression with the *esculenta* species (Mendes, 1982; Byrne, 1984).

REPRODUCTION MODE AND FLORAL BIOLOGY

Cassava normally reproduces by vegetative propagation, although sexual seed production easily occurs in the species, creating genetic diversity at the farming level, which is the main source of cassava genetic diversity for the indigenous communities located in the Amazon forest (Second and Inglesias, 2000).

Cassava is a monoic species, with male and female flowers, occurring in the same inflorescence. The male flowers are more numerous and are formed in the upper part of the inflorescence while the female flowers are less numerous, and are found in the lower part of the inflorescences (Figure 1). It presents protoginia, that is, the female flowers open a week before the male flowers (Kawan et al., 1978; Fukuda, 1980). However, simultaneous opening of the male and female flowers can occur among the inflorescences of the same plant. Thus both self-pollination and cross - pollination occur naturally (Pereira, 1989). It is considered a preferential self-pollinating and highly heterozygous species due to the protoginic trait of the flower anthesis, the occurrence of male sterility and the strong endogamic depression caused by

Figure 1. Cassava inflorescence mandioca.

self-pollination. However, there is no genetic or physiological barrier that prevents self-pollination (Kawano, 1982). The strong endogamic depression, in addition to its plant propagation form, acts as a biological mechanism by which the high rate of heterozygosis of the species is maintained (Kawan et al., 1978).

Sexual seeds have been used by genetic breeding programs to create variability, due the wide segregation for almost all plant traits of plants which originate highly non-uniform (heterogeneous) populations. The cassava sexual seed also acts as a filter for viruses and other diseases and can be used as a cassava propagation alternative in cassava crop (Iglesias et al., 1994).

The organic reproductive structure of *M. esculenta* is typical of allogamous species. However, the crossing rate is easily manageable for breeding purposes, allowing from 100% self-pollination to 100% crosses (Valle, 1990).

FACTORS THAT INFLUENCE FLOWERING

Factors that influence cassava flowering include genotype, moisture, soil fertility, photoperiod and temperature.

Most cassava varieties are able to flower. It seems that there is a local association between the plant´s flowering ability and its branching habit. Varieties with little or no branching hardly flower, although, from the physiological point of view, the plant first flowers to then emit branches. Connor et al. (1981) observed that the branching rate in cassava decreases when the plants suffer water stress. Flowering onset was suspended in little-branched plants during the stress period while the flowering was only reduced in more branched plants.

Cassava flowering can be delayed or absent in low fertility soils (Cours, 1951). However, high flowering and fruit production have been observed in poor soils (CIAT, 1994). Keating et al. (1982) observed a high concentration of flowers in cassava varieties when the photoperiod was greater than 13.5 hours. Irikura et al. (1979) reported that 24°C is the ideal temperature for flowering in cassava and any alteration above or below this temperature reduced the appearance of flowers. Intense flowering under semi-arid altitude conditions (+ 800 m above sea level) and poor soils was observed in most accessions (1650), components of the cassava germplasm bank kept at Embrapa Cassava and Fruit Crop.

FACTORS THAT AFFECT HYBRIDIZATION AND SEED PRODUCTION

Factors that affect the hybridization process in cassava include non-flowering and/or low rate of flower production by some genotypes, lack of synchrony in the flowering period of the genotypes and male sterility. Different degrees of male sterility have been observed in cassava varieties (Bai, 1985). Cours (1951) studied the morphological variation of many cassava varieties and reported that 20% of the varieties presented deformed anthers and were sterile males. When assessing many varieties, Magoon et al. (1968) identified several levels of male sterility. Male sterility has been attributed to several causes, including the non-disjunction of the microspore (Jos et al., 1966; Magoon and Jos, 1969); abnormal tapetum behavior (Jos et al., 1966; Magoon et al., 1968); cytological anomalies (Jos et al., 1984) and functional male sterility (Jose and Bai, 1981) which is reflected in the absence of anther dehiscence.

GENETICS AND CYTOLOGY

Cassava is a diploid species, 2n = 36 chromosomes, with regular meiosis of 18 bivalents (Graner, 1935; Perry, 1943; Nasser, 1978) but of segmental alotetraploid origin with a base number of chromosomes x = 9 (Umanah and Hartman, 1973; Magoon et al., 1996). The absence of a polyploid series indicates this to be the degree of ploidy that allows the best adaptability of the genus, but does not

contribute to the knowledge of the phylogeny of the species (Valle, 1999).

TRAIT HEREDITY

Mendelian segregation has been observed for some cassava morphological traits. The genetic control of these traits, while not of great agronomic importance, can be used in linking studies among certain traits, in the characterization of the genome and in the distinction of crosses and self-pollinations. Graner (1942) determined that narrow-lobed leaves are a dominant trait controlled by a single gene and the brown color of the root skin is dominant over the white. Jos and Nair (1984) observed that male sterility in cassava is a recessive monogenic trait.

Campo (1988) studied the genetic control of some morphological traits in cassava and observed that the pale green in the stem collenchymas is dominant over dark green and controlled by a single gene; that the yellow in the root parenchyma is dominant over white and controlled by two genes, while the pale yellow color is controlled by a pair of genes in heterozygosis.

The stem in zigzag is a recessive trait, and it is frequently used as a marker gene in cross identification. Red is dominant over green in leaf nervures and has also been used to distinguish clones derived from crosses of these of self pollinations (Kawano et al., 1978).

SELECTION FOR YIELD

Root yield is correlated with several plant traits that are production components. These include root weight, canopy weight, number of roots per plant, plant height and the harvest index. Positive and significant correlations were confirmed among root yield, number of roots per plant and harvest index that indicate both the number of roots per plant and harvest index can be considered good criteria to selection for root productivity. (Kawan et al., 1978; Fukuda et al., 1983; Fukuda and Caldas, 1987). However, harvest index should be used with precaution in the selection process. Plants with high harvest indexes and little canopy yield, even when they present high root yield, are undesirable because they produce little propagation material. In this case, a high harvest index does not reflect a high root yield, but a low canopy yield (Fukuda, 1996).

Root yield and harvest index correlate negatively with plant height and canopy yield, indicating that genotypes with exaggerated plant development should be avoided in selection for root yield. It is important to observe the balance between root yield and canopy.

Root weight, canopy weight and total plant weight are efficient criteria in segregant populations for selection of individuals for root yield (Fukuda et al., 1987).

HYBRIDIZATION TECHNIQUES

Cassava hybridizations are normally carried out by two pollination methods, cross pollination and controlled pollination.

Open pollination - This is the simplest and most economic method used to obtain greater genetic variability. However, it presents the disadvantages of permitting self - pollination and loss of identity of the male parent. The success of this method depends on parents with the greatest number of desirable and complementary characteristics. It can be inefficient because a considerable quantity of pollen from undesirable genotypes takes part in the crosses, reducing the possibilities of obtaining superior segregant individuals (Bueno, 1985).

Open pollination techniques requires some basic information for use, such as the type of pollinating agents of the species, the dynamics of pollen transportation by these agents and the self-pollination rates. Cassava flowers produce nectar that attracts insects. Bees are generally the principal pollinating agents of cassava. Their period of greatest activity in Cruz das Almas-BA, is concentrated between 12.00 and 14.000 h, that coincides with the flower opening period, which may vary according to the local climatic conditions. Observations at the CIAT (Palmira) confirmed that these insects distribute about 90% of the pollen in a 10 m radius which determines the minimum distances among multiple crosses blocks to prevent contamination by foreign pollens.

Self-pollination can occur in the same plant between different inflorescences, or among plants of the same variety, physically separated in the field. The greatest probabilities of self-pollination in cassava occur in fields where there is only one genotype. Thus the use of models that maximize hybridization rates, minimize self - pollination rates and prevent contamination by foreign pollens is suggested. Thus the multiple crosses technique is the most recommended in cassava breeding.

Multiple crosses - multiple crosses among groups of genotypes in isolated fields are required for the

efficient use of this technique. According to Acosta-Espinoza (1985), the efficiency of this technique can be affected by at least six factors: a) the spacing and arrangement of the plants within each block; b) the degree of incompatibility among the genotypes; c) the flowering period and duration; d) the quality of the planted material; e) the pollinating insect activity and f) the prevailing wind direction. A genetically balanced population can be obtained by adding data on the flowering habit of the genotypes, especially flowering capacity, flowering onset time, number of flowers produced, synchronization of the the genotypes flowering period and anomalies such as male sterility and low seed production.

Following the prime number principle developed by Wright (1965), models for plant arrangement in multiple crosses blocks involve up to fifty genotypes. Based on the same principle, Olesen and Olesen (1973) developed formulas for multiple cross design. Each clone is repeated the same number of times in each crossing block. The probability of reciprocal crosses among all the parents is high in this type of distribution and there is a possibility of self-pollination. All genotypes are labeled for easy identification of the mother plant at seed harvest. The fruit can be placed in bags to prevent seed losses due to dehiscence, or removed from the plants when ripe and exposed to the sun, or placed in continuous exhaustion ovens at 60°C to release the seeds. This method is used by the Embrapa Cassava and Fruit Crop and by several other cassava breeding programs. The individuals resulting from this type of cross have wide phenotypic variability.

Controlled pollination – It is considered the most efficient method because it controls the identity of both parents, female and male, removing the risk of undesirable crosses and self-pollination . However, the number of seeds produced per cross is lower and the cost is higher. Controlled pollination in cassava can be carried out manually (Fukuda, 1980; Hershey and Amaya, 1982) or by diallel crosses (Valle, 1990). Similarly to the multiple cross technique, knowledge on the flowering capacity, flowering onset and number of flowers produced is important, as well as the fertility level of the male parent.

Manual Pollination – Mechanical damage to the flower structures of the plant must be avoided for the successful use of this technique. Normally the male and female flowers do not mature at the same time in the same inflorescence, and the female flowers open some days after the male flowers. The female flowers should be protected before they open, on recognition of the flowers that will open during that day.

Flower size is an indicative of maturity although this characteristic depends on variety. However, safe prediction of female flower opening is based on the existence of a gelatinous droplet that forms in the flower interior. The cross field is visited in the morning to identify the individuals with flowers to be opened that day. By carefully removing the petal from the female and male flowers that have apparently reached their maximum development, the gelatinous droplet can be detected inside the flowers. The presence of this droplet is a safe indication that the flowers will open that day and therefore that they are ready and receptive to pollination and fertilization.

Female flowers that present droplets are then covered with cloth bags to protect them from contamination from foreign pollens in their opening period. Bags made from light fabrics are recommended to prevent the establishment of a micro-climate inside that is favorable to fungus development, especially anthracnose, that completely damages the recently formed fruit. The bags should measure 20 cm x 15 cm, and have a cord around the opening to tie them to the branches with inflorescence.

Fruit, male flowers, fertilized female flowers or flowers that have not opened, should be cut off with scissors. At the same time male flowers should be collected and placed in wide-toped flasks, previously identified and disinfected with alcohol. Male flowers are collected early because the flower opening period is very short, that determines the quick dispersal of the pollen grains by insects and pollen grain contamination. The contact of the anthers with the female flower stigma is enough to ensure pollination (Figure 2).

One male flower pollinates three to five female flowers on average. After pollination, labels should be placed on the panicles containing information on the parent names, number of flower pollinated, and pollination date. The already formed fruit should be covered eight days after pollination to avoid penetration and damage caused by insects, especially *Anastrepha* sp, and seed loss due to fruit dehiscence. The presence of a small white hair should be observed at this moment, resulting from oviposition of *Anastrepha* sp. Whenever present, the hair should be removed with a penknife, preventing larva penetration and development that could seriously damage the seeds.

Some breeders recommend covering the flower immediately after pollination to prevent contamination by other pollens and early infestation by *Anastrepha* sp. However, this practice causes greater losses in the pollinated flowers. Each cross produces an

Figura 2. Manual crossing.

average of two seeds. The fertilization percentage depends on the efficient application of the technique and pollen viability. Up to 80% success can be attained (Fukuda, 1980) when pollination is carried out without problems. A well-trained technician can pollinate up to 60 flowers a day. Two and a half to three months are necessary for fruit formation, maturity and dehiscence.

Diallel crosses – This technique was used by Valle in 1990. To obtain all the possible genetic combinations, the number of crossing blocks should correspond to the number of each parental pollinator. Two rows of twenty plants of each female parent clone were planted in each field, alternated with a row of twenty male parent plants. The plants used as females were systematically emasculated. Thus the seeds collected from these plants were derived from crosses of this cultivar with the pollinating cultivar, and the seeds collected from the pollinating plants resulted from self- pollination. In this case, the use of sterile male genotypes eliminated the risks of self-pollination and reduced emasculation costs. The fields were cultivated in isolation and far from any cassava plantation. The fruits were protected with cloth bags, as predicted by the manual and multiple cross fields. Information on the flowering onset and synchrony of the genotypes is essential for this technique to be efficient.

BREEDING OBJECTIVES

The objectives of a cassava breeding program depend on the yield, processing and market demands and should be country or region specific. However, programs may have objectives in common especially for increased root yield, disease and pest resistance. They should be dynamic and adjusted to crop evolution, within a context that involves expansion of the cultivated area, diversification of the end product and opportunities for alternative markets (Fukuda, 1994).

Program objectives have not been limited to the breeding of a single trait in cassava, and sometimes multiple traits are involved. Evidence shows that most of the traits of agronomic interest in the crop are controlled by several genes with additive effects. Thus the process is complex and slow.

The ecosystem and the exploitation purpose of the cultivar are considered regardless of the number of traits to be improved. Although it adapts to different edapho-climatic conditions, cassava presents high genotype and environment interaction, so that the same genotype is unlikely to behave in the same way in all ecological systems. One of the most important causes for this behavior is the large number of pests and diseases that affect the crop whose incidence and seriousness are limited to specific edapho-climatic conditions and restricted to certain ecosystems (Lozano et al., 1982). Furthermore, cassava is affected by many environmental stresses that limit or prevent development of a single variety in different localities. Consequently, the basic objectives of the cassava breeding programs should include the adaptation, yield stability and resistance to pests and diseases.

Disease resistance is of prime concern, especially to root rot caused by *Fusarium* spp and *Phytophthora* sp., bacteriosis (*Xanthomonas campestris* pv *manihotis*), frog skin, caused by virus and ver-sprouting caused by phytoplasms. In Africa, the main objective of the cassava breeding programs is the development of African Mosaic virus resistance, a disease that has not yet been reported in Latin America.

Resistance to spider mites is emphasized since they are very common in the Brazilian Northeast and the Cerrados. In addition, adaptation to abiotic stresses, drought resistance, tolerance to soils with high aluminum content (Cerrados) and cold conditions (subtropical) should be considered.

Cassava root and canopy are used in many ways. Besides root yield potential, the specific objectives of cassava breeding vary depending on its end purpose, which may be for industry, fresh consumption or animal nutrition.

The main objectives for industry are high starch and flour contents (>30%); for human consumption, low cyanic acid contents in the roots (<50 ppm), quick

cooking (< 30 min) and culinary quality when cooked, and for animal nutrition, where the whole plant is considered, the main objectives are canopy yield, with good leaf retention and high protein content and dry matter yield.

BREEDING METHODS

Cassava breeding methods are basically defined by its reproduction mode, genetic variability available, propagation mode and program objectives.

Some factors influence the choice of breeding methods in cassava, such as species, genetic and cytological characteristics of the species, endogamy level, flowering habit and plant pollination, low rate of seed production per pollination and its vegetative plant propagation mode. There is further male sterility, common in the species, and its high degree of heterozygosis.

Cassava presents ample segregation in the first generation after hybridization because it is a highly heterozygous self-pollinating species. Once a superior hybrid has been identified in the first generation, it is fixed by vegetative propagation (cloned), which is the greatest advantage of the species in breeding studies. On the other hand, the main disadvantages are the need to work with large populations, the difficulty in getting a precise estimation of the performance of the genotypes generated, and the low rate of vegetative propagation.

No classic breeding methods have been developed for vegetative propagation crops. Normally the methods developed for self-pollinating crops are applied to the cassava crop modified because of its specific characteristics. It has been pointed out, however, that few more sophisticated breeding methods have been applied to cassava compared to other crops.

The main breeding methods used in cassava cultivation are variety introduction and selection, intra - and interspecific hybridizations and polyploidy induction.

Variety introduction and selection - some breeders question the introduction of varieties as a breeding method, however, this is the most common method of developing new varieties of cassava. Introduction, followed by careful evaluation, is not only the simplest and least expensive method used, but also the one with the greatest chance of success because of the wide genetic diversity available, which has been little exploited. Generally the varieties introduced are collected in a region similar to that where the breeding research is being carried out, where there is probably greater genetic diversity for adaptation and resistance to local pests and diseases. The assessment and selection of the varieties introduced involve the formation of a study collection, followed by yield tests and tests with producer participation in various localities and years, within the same ecosystem (Fukuda, 1996).

Intraspecific hybridization – Intraspecific hybridization followed by selection is the most common method used in cassava when variability needs to be generated or characteristics of economic interest need to be transferred. Crosses are carried out among parents of the same species, carriers of complementary characteristics, based on their performance by years and localities. The success of this method depends basically on correct parent choice and efficient selection of genotypes with the progeny resulting from each cross. Parent selection is based on the phenotypic assessment of the varieties and their general and specific combining abilities, estimated by the performance of the respective progeny. A large population should be used to obtain the types of desirable recombinants. Thus more than fifty seeds per cross are recommended. Since the cassava varieties are highly heterozygous for most of the gene loci, segregation occurs in the first generation. The F1 hybrids are first selected in the seedling phase of the individuals within the segregant families (progeny). Then each selected individual is propagated vegetatively and the new clone is assessed by yield tests, as it occurs when the selection is on the varieties in the germplasm collection (Figure 3). As the new clone is derived from a single plant, the process is slower because of the low propagation rate of the crop.

Interspecific hybridization – Most breeders consider the use of wild species as the last alternative to breeding a particular trait (Hershey, 1987). Interspecific hybridization in cassava has potential but must be used on a larger scale after a complete understanding and exploration of the genetic diversity of the *M. esculenta* species and/or whenever the modification of some characteristics of the species are desired (Fukuda, 1999).

On the other hand, Hershey (1987) pointed out that the potential use of other species of the *Manihot* genus in cassava breeding is disputable, considering that genetic diversity for almost all the agronomic traits of economic value has already been identified in the germplasm of the available *M. esculenta* species. Generally when a cultivated genotype is crossed with a wild species, carrier of favorable alleles for a certain characteristic, a series of unfavorable alleles for other

agronomic characteristics that require a series of generations of back crosses to recover the original characteristics of the genotype are also transferred.

Jennings (1959) stated that interspecific hybrids in *Manihot* occur frequently, and can be obtained with relative ease. Evidence of reproductive barriers strong enough to prevent crosses between cassava and similar species has not yet been found. However, Nasser et al. (1986) observed, among a series of successful crosses, some failures in crosses between *M. glaziovii*

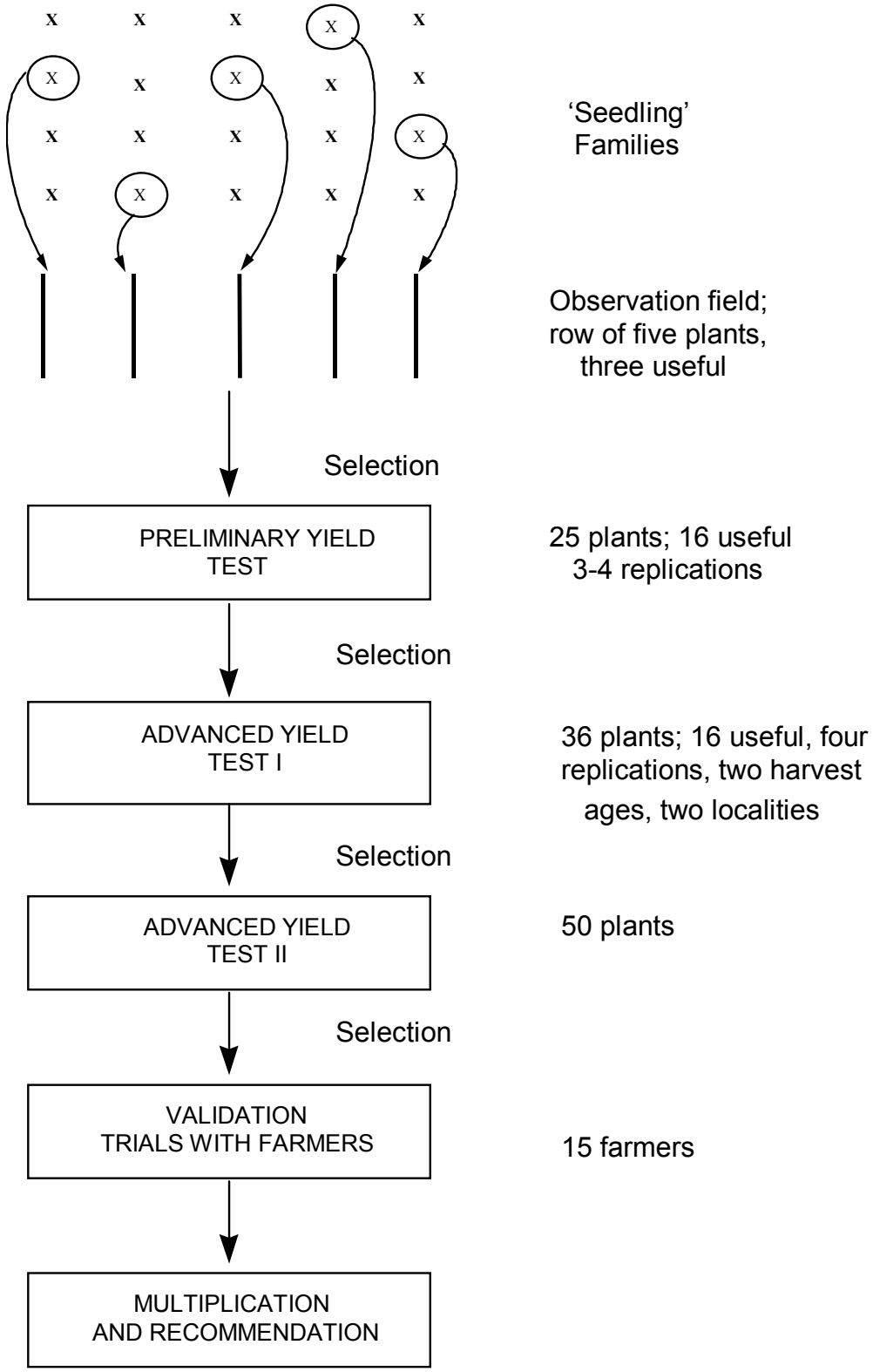

Figure 3. Cassava hybrid scheme of evaluation and selection

and *M. esculenta* . Partial pollen sterility was observed in Africa, in F1 hybrids obtained from crosses between *M. glaziovii* and *M. sculenta* (Lefévre, 1989). Hybridizations between *M. esculenta* and *M. glaziovii* carried out in Africa to transfer African Mosaic resistance to cassava varieties were very successful (Valle, 1991).

Studies are still incomplete, but the evidence favors the theory that most of the wild species of the *Manihot* genus are part of the primary or secondary cassava 'gene pool´. In spite of the wide genetic diversity within the different 'gene pools´ of the *Manihot* genus, only one successful case regarding the transference of African Mosaic Virus resistance from *M. glaziovii* to *M. esculenta*, using wild species in cassava breeding, has been published to date, The use of the genetic diversity of some wild species of the *Manihot* genus began in 1930 in Africa to meet the need for resistance to African Mosaic in the local cultivars (Jennings, 1957). After many years of limited progress in cassava breeding in many centers in Africa, there was a change of direction [breakthrough] when the Amani program in Tanzania and the Lake Alaotra program in Madagascar began to use the wild species (*M. dichotoma* Ule, *M. catingae* Ule, *M. prinlei* Watson and 'Tree Cassava´, a natural hybrid between *M. glaziovii* and *M. esculenta*), when *M. glaziovii* was used to transfer African Mosaic virus resistance. After three or four back cross cycles, which took 15 years, the desirable characteristics were restored to the varieties of the *M. esculenta* species and the undesirable characteristics of the wild species were eliminated. However, only the hybrids with *M. glaziovii* were successful (Nichols, 1947; Jennings, 1957). The germplasm derived from the West Africa genetic breeding program has been the main source of African Mosaic virus resistance (Jennings, 1976; Jennings and Herschey 1987).

Other uses of wild species of the *Manihot* genus in cassava breeding have been reported, but less extensively (Nassar et al., 1986; Bonierbale et al., 1997). IITA has used several wild *Manihot* species in interspecific crosses to transfer other desirable genes to cassava (Asiedu et al., 1994).

Polyploidy induction – The polyploidy induction method has been little used. It is based on the premise that polyploidy is associated to certain characteristics of the plant such as canopy vigor, including larger, thicker leaves and good leaf retention. Polyploidy induction has been the subject of studies in India by Streekumari et al. (1995) with treatment with colchicine.

Spontaneous polyploids, sexual and asexual, from intra and interspecific crosses, have been tested for their agronomic value. These crosses have been promising and represent a new perspective for broadening the cassava genetic base (Hahn et al., 1990; Asiedu et al., 1994; Streekumari et al., 1995).

Use of biotechnology – Significant gains in terms of yield, adaptation and quality have been obtained using conventional breeding methods in cassava (Hershey and Jennings, 1992). However, the real gains in yield in the cassava producing countries have not been equivalent to the gains obtained at the experimental level, except in some Asian countries (Kawano, 1998).

Progress in breeding programs will be accelerated in the near future with the introduction of various biotechnology techniques such as genetic transformation and marker assisted selection. These new techniques will play an important role in evaluating characteristics that are difficult to asses or that have a narrow genetic diversity within the gene pool of the cultivated species.

Marker assisted selection – CIAT has concentrated efforts in constructing the cassava genetic map and in finding practical applications for the assisted breeding of this crop. Fregene et al. (1997) have made considerable progress in the construction of the cassava genetic map. This map was developed based on an F1 progeny derived from crosses among genetically distant crosses from Latin America and Africa. A mean density of one marker per 7.9 cM was detected, using RLFP, RAPDs microsatellite and enzyme marker methods. More recently, Mba et al. (2001) published the results of the efforts made to develop a saturated consensus map using microsatellites.

The molecular map is already being used to understand the genetics of important traits. A scheme to ascertain the use of molecular markers in the assessment of segregant populations for bacteriosis resistance was proposed by Jorge et al. (2000), who detected several QTL´s that explained a considerable proportion of trait variability. The extension of the QTL´s relationship with the expression of bacteriosis in the field was recently studied by Jorge et al. (2001), who discovered a particular QTL in the D linking group that correlated *we*ll with the degree of disease infestation. The pathogen population structure is extremely variable and further studies are needed to confirm the stability of the QLT´s by years and localities before breeders can apply them routinely to their breeding programs for bacteriosis resistance.

CIAT and IITA have begun a study to relate molecular markers with the genotype reaction to African Mosaic

virus (Fregene et al., 2000). African landrace varieties resistant to African Mosaic have been identified as genetically different from susceptible landraces and from resistant elite varieties. Although specific regions of the genome have not yet been defined with high correlation in terms of reaction to the disease, considerable progress has been made in Africa towards understanding the processes of genetic divergence as well as using and exploiting sources of resistance to such devastating diseases as African Mosaic.

The application of molecular markers in cassava root post-harvest deterioration is being studied at the University of Bath and CIAT. Their objective is to identify the key genes that act during the root deterioration process for future alteration. Genes that play key roles in the deterioration process of other crops have been identified by Beeching et al. (1994) and are presently being mapped by Cortez et al. (2001).

With the advent of quicker and cheaper methods for DNA isolation and characterization, assisted breeding will become a routine tool to help breeders have a better understanding of the utilization of the traits that have received little attention from conventional breeding methodologies.

Genetic transformation in cassava - Genetic engineering plays a special role in the breeding of vegetatively propagated heterozygous plants such as cassava. Important genes can be introduced in local or adapted varieties without changing other desirable characteristics. This way, all the desirable combinations that make producers prefer a variety is kept, and the bred genotype can be widely adopted.

This advantage, in particular, was not exploited for many years because plants could not be regenerated from the transformation of a single cell or from somatic tissues. Success in cassava genetic transformation was obtained in the 1990's with the introduction of the friable embryonic stem culture and the suspension system culture (Taylor et al., 1996; Schoeple et al., 1996). Cassava plant regeneration studies via organogenesis have been published recently by Li et al. (1998). These regeneration methods have opened new opportunities for the application of different transformation systems.

Raemakers et al. (1997) first reported the use of *Agrobacterium tumefaciens* in genetic transformation. The anti-sense constructors for starch grain synthesis, isoform I and II, ramified in enzyme and ADP–glucose pyrophosphorylase, isolated by Munyikwa et al. (1997), were incorporated in the cassava genome, resulting in wax type genotypes and other starch variants that may open new markets for the industrial use of cassava. A group at CIAT has reported on a successful experience with the introgression of a gene that confers resistance to herbicide using *Agrobacterium* as mediator in transformation techniques (Sarria et al., 2000).

A refined protocol to produce stable transformation in cassava plants using particle bombardment was reported by Zhang et al. (2000). The same group has also published results on the success of transformation in cassava plants using non-positive selection for antibiotics (Zhang and Pounti-Kaerlas, 2000).

Advances in transformation techniques in cassava will contribute to a considerable widening of its genetic base. Genetic transformation will soon provide routine support to breeding programs since attributes such as a layer of protein conferring resistance to main viruses, starches with specific quality for industry and amplification of the physiological traits have become extremely important to cassava cultivation.

NEW VARIETY DIFFUSION

Once breeders and producers have bred and selected new cassava varieties they must be multiplied and distributed to achieve the required economic and social impact. However, there is a series of factors inherent to the biological characteristics of the cassava crop that hinder the process of variety diffusion such as the long cycle, low seed multiplication rate and the storage problems of the stem-seeds which reduce the quality of planting materials (Henry and Inglesias, 1993).

Cassava is potentially susceptible to various pests and diseases, many of which affect the quality and quantity of planting material and can be transmitted from one crop cycle to another (Inglesias et al., 1994). *In vitro* propagation techniques and heat therapy have been applied as the first step in multiplying the most important varieties (Roca et al., 1989; Konan et al., 1997); however, there is a considerable probability of re-infection after some years of multiplication in the field.

Considering all these factors, several multiplication systems have been assessed with different degrees of success. The most recommended system is based on decentralized production of planting materials with good nutritional and health quality. Farmers known for their good cassava cultivation practices and who are community leaders are encouraged to produce and distribute planting materials of the most important

varieties. These farmers in turn renew their stocks from materials supplied by regional centers that keep small seed banks in their bases. Planting materials from these seed banks are derived from plants kept in the field or *in vitro* by experimental station breeders (Lopez, 1994).

The release of bred cassava varieties through formal channels has met with varied success. According to Inglesias (1994) the characteristics offered by new varieties to solve the farmers´ and consumers´ most urgent problems are key factors for the dissemination, diffusion and adoption of new cassava varieties. Therefore the integration of participatory research methodologies as a channel for selection and diffusion is essential (Iglesias and Hernandez, 2000). Fukuda and Saad described an integrated participative system of assessment and multiplication followed by formal and informal diffusion of preferred genotypes. The integration of phytosanitary and nutritional management of the planting material in the participative research scheme will result in an ideal methodology to attain a wide base of impact for breeding programs.

CURRENT STATE OF BREEDING

A series of events in the 1990's outlines the current state of cassava breeding: a) reduction in financing organs for research into cassava at global level and in most countries; b) an increased interest on the part of private enterprise to promote cassava processing and support applied research; c) incorporation of participative research methodologies with farmers in the conventional breeding programs; d) application of biotechnology as a tool to solve important problems; d) increase in exchange among cassava research scientists.

Funding has been considerably reduced for cassava research in the international research centers. CIAT and IITA have concentrated efforts on maintenance, characterization and use of their germplasm banks, with significant reduction in the research activities of breeding and crop management (Scott et al., 2000). A similar situation has occurred in countries traditionally known as pioneers in cassava research such as Brazil, Thailand and Nigeria, where funds for research into this crop have been reduced although the crop is vital to the economy.

On the other hand, there is a greater involvement of the private sector in financing research activities that may produce effects in the short term on industrial cassava development. Tests with varieties and seed multiplication have been given high priority. Consequently a consortium has been set up recently in Latin America (CIAT, 2000) to support research related to cassava starch quality (Carvalho et al., 2000) and industry is actively involved in tests and variety dissemination in Asia (Pustipitorini et al., 1998).

Participative research methods in cassava breeding, introduced in the 1990's, represent one of the most positive changes to make breeding programs more effective. The methodology consists of obtaining feedback for the programs from the farmers, making available a greater diversity of genotypes and involving the farmers in the multiplication and transfers process of the best varieties they selected.

Although biotechnology has not been widely developed or applied in cassava, it has already contributed to improving the efficiency of the established programs. *In vitro* multiplication and indexation for diseases has contributed to the dissemination of good quality planting materials. Pathogen molecular characterization is a guide to assess and discard cassava genotypes for integrated pest and disease management (Jorge et al., 2001). Although they are not yet in the field, cassava cultivars transformed for waxy starch (Munyikwa et al., 1997) and resistance to the Basta herbicide (Sarria et al., 2000) are being assessed according to the biosafety protocol and may soon be planted commercially.

The significant reduction in resources and efforts for cassava breeding has been compensated by the increase in the exchange of ideas and germplasm resulting from the various breeding programs that has raised the level of communication among breeders.

Cassava breeders are working in less isolation and with more open minds, directed to a better integration with scientists in a similar situation (Hershey, 1991; Inglesias and Fukuda, 1992; Inglesias, 1994).

MAIN RESULTS AND IMPACTS

The main objective of breeding programs is to develop varieties superior to those currently cultivated, especially for the economic and/or biologically important traits that are accepted by producers, processors and consumers. The success in cassava breeding has had significant economic impacts in areas of greater production, where adoption is quicker and there are more concrete demands from producers. The process of adopting bred varieties has increased among small farmers with the introduction of participative methodologies in cassava breeding, especially in the Brazilian northeast (Fukuda et al., 2000) thus enabling the impacts to be studied.

THE FUTURE OF BREEDING

The extensive cassava genetic diversity available will be increased in the future with use of genetic sources from wild species, in association with those with genetic transformation protocols. These two alternatives will help to direct breeding for those traits that have narrow genetic diversity such as quality, or do not exist within the germplasm available for the cultivated species, such as resistance to the stem borer.

Although only a small percentage of the total cassava genetic diversity available has been used by the conventional breeding programs and several studies are being developed in the areas of genetic distances, genomic complementation, genome region detection with wide effects on highly important traits, the assessed germplasm will continue to be used for its phenotypic characteristics, as in other crops (Transkly and McCouch, 1997).

Around 2020 the roots and tubers will integrate the emerging market because of their production efficiency, adaptation and the wide diversity of highly competitive, high quality products for human and animal nutrition and for industry. These products with adaptation to marginal zones will contribute to food safety because of their great flexibility in adapting to mixed cropping systems, becoming important components in the strategies to improve the life of small farmers in the field, linking the them to this growing emergent market (Scott et al., 2000).

Within this context the conventional cassava breeding methods still have much to offer in terms of increasing their adaptation potential, production and quality. Studies in partnership with the end user (farmers, consumers and processors) and with institutions involved in basic research will play an important role in the expression of this potential (Fukuda, 1994). The potential for production and quality in the field is the result of the genotype environment interaction or specific production conditions. Breeders should pay more attention to these interactions to maximize the gains observed in the experimental stations in the field.

There are other challenges that may require investment and dedication from a cassava breeding team (CIAT, 1994). Basic research, including biotechnology, is the key to the following challenges: a) development of very low cyanogenic acid content genotypes; b) reduction or elimination of post-harvest deterioration; c) genotypes with specific starches; d) increase in stress tolerance combined with protection mechanisms for poor environments; e) solving the plant propagation problems and f) making the crop more suitable for mechanization.

Recommended cultivars in Brazil

The cultivar is one of the main technological components of cassava production because of its capacity to adapt to the most different cropping conditions and to be an undemanding crop in terms of inputs and water. Furthermore, some pest and disease problems can be solved with the use of resistant cultivars.

Cassava cultivars are normally classified as sweet or bitter depending on the cyanic acid content (HCN) in their roots (Rogers and Appan, 1973). The sweet cultivars are also known as ‘aipim´, ‘macaxeira´ or ‘soft´ cassava and the bitter cultivars as ‘fierce´ cassava. From this definition the cultivars are used for fresh human or animal consumption, and/or processed.

Table cultivars – the main characteristic of cultivars used for human consumption concerns their cyanic acid content (HCN) in the roots that must be less than 50mg/kg roots. The HCN content varies with the cultivar, age at harvest and environment conditions.

Thus significant differences were observed in the HCN contents in cultivars harvested between the 6th and 16th month according to the harvest age within the same variety (Fukuda & Borges, 1990). Therefore

Table 1. Cassava cultivares recommended for Northern Brazil.

Variety	Root Yield (t/ha)	Starch content (%)	Type	Disease resistance	Root film color	Skin color without film	Raw Pulp color	Recommendation	
								Institution	Locality
BRS Purus	25.0	26.0	Bitter	Root rot	Dark Brown	-	Cream	CPAA[1]	Amazônia
Zolhudinha	33.0	32.0	Bitter	Root rot	Dark Brown	-	Yellow	CPAA	Amazônia
Mãe Joana	19.0	32.0	Bitter	Root rot	Pale Brown	-	Pale Yellow	CPAA	Amazônia
Amazonas Embrapa 8	25.0	32.0	Bitter	Root rot	Dark Brown	-	Pale Yellow	CPAA	Amazônia

[1] Embrapa Amazonas Ocidental.

harvest age is a definitive factor in cassava cultivar choice. Many cultivars, however, are fairly stable for this factor, which should be assessed before a table cultivar is recommended for adoption.

The root cooking time, a critical factor for the *in natura* market, also varies according to the age of the plant. It is very common for cassava varieties to have a certain period in their cycle without presenting cooking conditions. On the other hand, others can be cooked throughout their cycle (Fukuda and Borges, 1990). Other traits for quality, such as taste, plasticity, stickiness and absence of fibers when cooked, resistance to post-harvest deterioration, easy root peeling and root size and shape are fundamental for the table cassava consumer market and should be considered when choosing the cultivar. Cassava cultivars for the table generally should have a shorter cycle to maintain end product quality. Late cultivars do not usually cook at the end of the cycle and when they do their quality is poor, especially because they present fibers.

Table 2. Cassava cultivars recommended for Northeastern Brazil.

Variety	Root yield (t/ha)	Starch content (%)	Type	Disease resistance	Skin film color	Skin color without film	Raw pulp color	Recommendation	
								Institution	Locality
Jussara	26.7	25.0	Bitter	-	Cream	White	White	CNPMF [1/]	Bahia
Valença	35.1	32.0	Bitter	-	Pale Brown	White	White	CNPMF	Bahia
Caetité	30.0	33.0	Bitter	-	Dark Brown	Cream	White	CNPMF	Bahia
Catulina	34.5	30.0	Bitter	-	Cream	White	White	CNPMF	Bahia
Bibiana	25.3	26.0	Bitter	Root rot	Pale Brown	Pink	White	CNPMF	Bahia
Crioula (8611/18)	18.0	33.0	-	-	Pale Brown	-	White	CNPMF	Bahia
Mestiça (8707/02)	26.0	31.0	-	-	Pale Brown	-	White	CNPMF	Bahia
Saracura	45.8	30.9	Sweet	-	Dark Brown	Pinkish	White	CNPMF	Bahia
Maragogipe	33.0	29.2	Sweet	-	Pale Brown	White	White	CNPMF	Bahia
Casca Roxa	29.1	30.4	Sweet	-	Dark Brown	Pinkish	White	CNPMF	Bahia
Manteiga	24.4	31.1	Sweet	-	Dark Brown	Purple	Cream	CNPMF	Bahia
Paraguai	15.2	24.4	Sweet	-	Dark Brown	Cream	White	CNPMF	Bahia
Salamandra	18.5	33.0	-	Oversprouting	Cream	-	White	CNPMF	Bahia
Tianguá	13.2	34.0	-	Oversprouting	Dark Brown	-	White	CNPMF	Bahia
Ubajara	23.7	32.0	-	Oversprouting	Pale Brown	-	White	CNPMF	Bahia
Ibiapaba	20.0	37.7	-	Oversprout.ng	Dark Brown	-	Cream	CNPMF	Bahia
BGM 260 (Rosa)	20.6	28.0	Bitter	-	Dark Brown	-	White	CNPMF	Ceará
BGM 549 (ASweet Burro)	26.7	30.0	Bitter	-	Dark Brown	-	White	CNPMF	Ceará
Kiriris	33.8	30.0	-	Resistant	Dark Brown	-	White	CNPMF	Sergipe
Aramaris	26.6	26.6	-	Resistant	Yellow	-	White	CNPMF	Sergipe
Aipim Brasil	15.0	30.0	Sweet	-	White	-	White	CNPMF	Bahia

[1/] Embrapa Mandioca e Fruticultura.

Table 3. Cassava cultivars recommended for Southeastern Brazil.

Variety	Root yield (t/ha)	Starch content (%)	Type	Disease resistance	Root film color	Skin color without film	Raw pulp color	Recommendation	
								Institution	Locality
B. de S. Catarina	20.8	25.0	Bitter	Bacteriosis	White	White	White	IAC[1/]	São Paulo
Mico	21.2	20.3	Bitter	Bacteriosis	Brown	White	White	IAC	São Paulo
Fibra	20.8	25.3	Bitter	Bacteriosis	White	White	White	IAC	São Paulo
IAC-12-829	21.8	30.4	Bitter	Bacteriosis	Brown	White	White	IAC	São Paulo
IAC 24-2	26.1	26.2*	Sweet	Bacteriosis	Brown	Róseo	White	IAC	São Paulo
IAC 14-18	20.0	30.0	Sweet	Bacteriosis	Brown	White	White	IAC	São Paulo
IAC 352-7	21.2	28.0*	Sweet	Bacteriosis	Brown	White	White	IAC	São Paulo
IAC 59-210	25.4	30.0*	Sweet	Bacteriosis	Brown	White	White	IAC	São Paulo
IAC 576-70	29.9	28.0*	Sweet	Bacteriosis	Brown	Cream	Yellow	IAC	São Paulo

[1/] Instituto Agronômico de Campinas; [2] Cerrados.

Table 4. Cassava cultivares recommended for Central Western Brazil.

Variety	Root yield (t/ha)	Starch content (%)	Type	Disease resistance	Root film color	Skin color without film	Pulp color	Recommendation	
								Institution	Locality
IAC-24-2	16.0	26.0	Sweet	Bacteriosis	Brown	Pinkish	White	CPAC[1/]	Minas Gerais
IAC 352-6	16.0	25.0	Sweet	Bacteriosis	Brown	Cream	White	CPAC	Minas Gerais
IAC 352-7	20.0	28.0	Sweet	Bacteriosis	Brown	White	White	CPAC	Minas Gerais
IAC 12 829	20.0	33.0	Médio	Tolerante	Brown	White	White	CPAC	Minas Gerais
IAC 7-127	28.0	32.0	Bitter	Tolerante	Brown	White	White	CPAC	Minas Gerais
Sonora	28.0	28.0	Bitter	Tolerante	Brown	White	White	CPAC	Minas Gerais
EAB – 81	30.0	31.0	Médio	Tolerante	Brown	White	White	CPAC	Minas Gerais
EAB – 653	28.0	20.0	Bitter	Bacteriosis	Brown	White	White	CPAC	Minas Gerais

[1/] Embrapa Cerrados.

Table 5. Cassava cultivares recommended for South Brazil.

Variety	Root yield (t/há)	Starch content (%)	Type	Disease resistance	Root film color	Skin color without film	Raw pulp color	Recommentation	
								Institution	Locality
Fibra	50.0	high	Bitter	Bacteriosis	Pale	White	White	Farmer	Paraná
Olho Junto	60.0	high	Bitter	Bacteriosis	Brown	Pinkish	White	Farmer	Paraná
Fécula White	65.0	high	Sweet	Bacteriosis	Pale	White	White	Farmer	Paraná
Mico	60.0	high	Bitter	Bacteriosis	Brown	White	White	Farmer	Paraná
IAC 13	22.6	high	Bitter	Bacteriosis	Pale	White	White	Farmer	Paraná
IAC 14	40.0	high	Sweet	Bacteriosis	Brown	White	White	Farmer	Paraná
Espeto	50.0	high	Sweet	Bacteriosis	Pale	White	White	Farmer	Paraná

Cultivars for industry – Cassava cultivars for industry should be selected according to their end use. Sweet and fierce varieties can be used because the HCN content in the roots is released during processing. Industrialized cassava can give rise to many products and subproducts, especially the starch, also known as fécula, tapioca or starch, flour, scrapings (raspa), products for bread making and pasta (Matsuura and Folgatti, 2000). In these cases, the cassava cultivars should present characteristics such as high starch and high flour yield and quality. Furthermore, it is important in most regions in Brazil that the cultivars present roots with white pulp and cortex and fine white skin for flour and starch production that makes peeling easy and ensures end product quality. Roots with yellow pulp are preferred for flour production in the North of Brazil and in Maranhão state, and a great variability of cassava with yellow pulp roots may be found in that region. The yellow pulp characteristic can also be important from a nutritional point of view, in both the fierce and sweet varieties because of the high beta-carotene contents, vitamin A precursor, found in the roots of these varieties (Carvalho, 2000a).

Cultivars for animal nutrition – the whole cassava plant can be used in the nutrition of various types of domestic animals such as cattle, poultry and pigs. The roots are sources of carbohydrates and the canopy, including the shoots, supplies carbohydrates and proteins, the latter concentrated in the leaves. These cultivars ideally present high root, dry matter and canopy yields. When the roots are selected for animal nutrition, varieties with high root dry matter yield should be chosen. When the canopy is used, cultivars presenting high fresh matter yield, high protein contents and good leaf retention are important. Furthermore, cultivars with low HCN leaf contents should be used.

Cultivars for different ecosystems

Although it adapts to very different ecosystems, cassava cultivation presents a high genotype-environment interaction, that is, the cultivars have specific adaptation to certain regions and the same cultivar will not behave in the same way in all the ecosystems. The reasons for this are the different climatic and soil conditions and the many pests and diseases that affect

cassava cultivation that are restricted to certain environments. This also justifies in part the great diversity of cultivars used by Brazilian cassava farmers. Thus the selection and breeding studies on the crop in Brazil, as in research for the different forms of use, are also directed to specific ecosystems. It was chosen to present the cultivars selected by Ecogeographic region because the different regions of Brazil present different ecosystems and use cassava in different ways.

In the Northern region cassava is used to make table flour and 'tucupi´ and the main demand is for cultivars with high root yield resistant to root rot with yellow-colored pulp. Table 1 shows cultivars recommended for the region, most resulting from selection by farmers. They include Bubão (flour), Pretinha (flour) and Mandioca Branca. The latter, according to Albuquerque (1969) is a sweet cultivar much used for porridge because it is very poor in starch (5%). Currently it has also been used to manufacture natural honey because of its high glucose content (Carvalho, 2000b). Other important cultivars are Amazonas (sweet), used to manufacture tucupí, because of its purple color and leaves that are used for maniçoba (typical dish); Pecuí for flour, Mameluca for fécula and flour; Xingú for flour and tucupi, because it is yellow, and Juruará, for fécula and flour (Alburquerque, 1969).

Water stress, spider mites and root rot are the main problems that affect cassava cultivation in the Northeastern Region. Cassava is mainly used in this region in flour and 'beiju´ (wafer) manufacture. Research has recommended many cultivars for the Northeast, some of which are shown in Table 2.

Although many cultivars have been recommended by research for the Northeast, most grown in this Region are the results of selection by farmers. The most grown cultivars include 'Bujá, 'Aciolina' and 'Fragosa', on the coast of Ceará; Cariri, Trouxinha, Engana Ladrão, Milagrosa and Olho Verde in Pernambuco; Platina, Cigana Preta, Olho Roxo, Corrente, Cidade Rica, Tola, Lazam, Aipim Cachorro and Cemitério in Bahia; 'Caravela' in Sergipe, in Piauí, Vermelhinha and Goela de Jacu and in Maranhão, 'Najazinha', 'Amarelinha' and 'Tomazinha'.

In the Southeast cassava is used for fécula, flour and fodder. Bacteriosis is the main problem that affects the crop in this region. Many cassava cultivars have been recommended by research for this region, especially for São Paulo state, by the Campinas Agronomic Institute that has developed a breeding program for cassava since the 1930s (Table 3).

Cassava is used mainly for flour manufacture and fodder in the Center-West, and is affected by many biotic and abiotic problems. Bacteriosis is the main disease and spider mites and Vatiga are the main pests especially in the Cerrados where they cause serious problems for the crops, especially during the six month drought, common in much of the region. The main cultivars are listed in Table 4. Farmers in the Central-western region also cultivate many others, including 'Vassourinha' and 'Cacau' in Minas Gerais State, 'Fitinha', 'Amarelinha', 'Olho Junto', 'Espeto' and 'Fécula Branca' in Mato Grosso and Mato Grosso do Sul states.

Cassava in the Southern Region is used to manufacture flour and fécula. Bacteriosis is the main problem that affects the crop and resistance to this disease is the main factor in cultivar recommendation. Large flour and fécula factories are installed in South , especially in Paraná state, that require cultivars with high starch yield and quality. The cassava cultivars most cultivated in Paraná state are Fibra, Olho Junto, Espeto, Fécula Branca, Mico, IAC 13 and IAC 14 (Tabela 4), mainly in Paranavaí, Cianorte, Campo Mourão and Umuarama (Takahashi and Gonçalo, 2001). The Mico, Aipim Gigante and Mandim Branca cultivars are the most planted in Santa Catarina state for use in the flour and fécula industries. In Rio Grande do Sul 'Taquari' and 'Pernambucana' were selected by the farmers and are the most planted.

RESUMO

Melhoramento de mandioca

São descritos os principais fatores relacionados ao melhoramento de mandioca, tais como: origem e domesticação, classificação botânica e relação com outras espécies, modo de reprodução e biologia floral, fatores que influenciam o florescimento, fatores que afetam a hibridação e produção de sementes, genética e citogenética, herança de caracteres qualitativos, critérios de seleção para rendimento, técnicas de hibridação, objetivos gerais e específicos do melhoramento, método de melhoramento, difusão de novas variedades, estado atual do melhoramento, principais resultados e impactos, futuro do melhoramento e cultivares recomendados no Brasil. Os principais resultados obtidos ao nível nacional e internacional nas áreas de germoplasma e do melhoramento genético de mandioca são discutidos. É apresentado uma lista com a descrição das cultivares selecionados nas diferentes regiões do Brasil.

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