Genet Resour Crop Evol (2007) 54:1523–1530
DOI 10.1007/s10722-006-9144-y

RESEARCH ARTICLE

Wild and indigenous cassava, *Manihot esculenta* Crantz diversity: An untapped genetic resource

Nagib M. A. Nassar

Received: 4 April 2006 / Accepted: 1 November 2006 / Published online: 11 April 2007

Abstract Cassava is the most important food for poor people in the tropics. Its roots are used either fresh or in numerous processed forms. It is a shrub with tuberous adventitious roots arising from stem cutting. Wild relatives of cassava are perennial and vary in growth pattern from nearly acaulescent subshrubs to small trees. They have been used as a source of useful characters such as high protein content, apomixis, resistance to mealy bug and mosaic disease and tolerance to drought. Cultivars stem from interspecific hybrids of cassava with *M. glaziovii* Muell.-Arg. are cultivated now in about 4 millions hectars in Nigeria. Indigenous clones are potential source of B-carotene and lycopene.

Keywords Carotenoids · High protein · *Manihot esculenta* · Mealy bug · Mosaic disease · Reproduction system

Introduction

Cassava, *Manihot esculenta* Crantz is cultivated throughout the lowland tropics. Typically the crop is grown between 30° North and 30° South of the equator, in areas where the annual mean temperature is greater than 18°C. It possesses many attributes such as efficient carbohydrate production (Coursey and Hynes 1970), tolerance of low soil fertility, recovery from damage caused by pests and diseases, insurance against famine via underground conservation for long periods, and its adaptation to mixed cropping systems. It is the sixth major staple crop in the world after rice, wheat, maize, potato, and sweet potato with annual production of 185 million tones (FAO 2003). Nigeria and Brazil accounts for about one third of the whole world production. The continent of Africa is responsible for more than half of the world production.

The root is principally used as a human food, either fresh (boiled, backed, fried or in numerous processed forms (Lancaster et al. 1982). According to FAO (2003) it is estimated that in 2003, more than 700 million people consumed cassava in one form or another. It is used for animal feed too, and as a raw material for producing starch, starch-based products and starch derivatives. Cassava starch is an important raw material in food processing, paper, textile and adhesive manufacturing and in oil drilling industry. It is also a raw material for producing many derived sugar products, such as glucose, maltodextrines and mannitol (Anonymous 1989).

Cassava is used principally for human consumption. While the main value comes from its

N. M. A. Nassar (✉)
Departamento de Genética, Universidade de Brasília, Brasilia, Brazil
e-mail: nagnassa@rudah.com.br

starchy roots, its leaves are eaten frequently in Africa. It contains 25–36% on a dry matter weight. Gari is the most popular form for consumption. To produce Gari, tubers are peeled, grated, pressed, sieved, toasted and separated into various particle sizes. In this kind of food as well as in other types, techniques and methods applied are designed to eliminate the poisonous cyanogenic glycoside from the roots.

Morphology

Cassava is a shrub, 1–3 m height with tuberous adventitious roots arising from stem cutting. Roots have various forms and shapes from long to slender to globose. The plant stem is woody and glabrous, but in some cases slightly pubescent, branched and predominantly brown, sometimes yellow or silver. Leaves are alternates, simples, stipuled and palmately lobed. The inflorescence is a panicle having bracts and bracteoles that are normally inconspicuous and caducous. Flowers are monoecious with pistillate ones few in number, positioned at the base. They open first (protogyneous). The staminate flowers are apical and numerous. Perianth is composed of five tepals. The ovary has a nonelobed disc, three carpellate. Staminate flowers have 10 stamens in two whorls. Pollen is large, and in many cultivars, sticky. Fruit is shizocarp, three lobes and usually winged. Seed is caranculate, elongate and frequently mottled brown. Cassava roots are composed of peel which is about 10–20% of the tuberous root. The cork layer represents 0.5–2.0% of the total tube weight. The edible fleshy portion makes up 80 or 90% of the tuber. It is composed of 60–65% water, 30–35% carbohydrate, 1–2% protein, 0.2–0% fat, 1–2% fiber, and 1–1.5% mineral matter of the tuber flesh (Nassar 1986; Nassar and Costa 1978; Nassar and Dorea 1982). The protein of cassava tuber is rich in argenine but is low in methionine and lysine. It seems that there is a relatively large amount of non-protein nitrogen in the root so that protein content estimated from nitrogen analysis tend to be higher than those estimated from amino acids, some of this non-protein nitrogen originated from glycosides. Hence, caution must be taken when selecting high protein content cultivars. It is possible that high protein cultivars are no more than high glycoside content cultivars (Nassar and Dorea 1982).

Growth

Cassava is a perennial plant. It is reproduced via by stem cuttings in production, but in plant breeding it is propagated in the first cycle from sexual seed. Stems when planted produce sprouts and adventitious roots within a week. Seed when used for propagation is slow germinating, and normally suffers from dormancy. Scarifying the seed and filing the micropylar end does not break dormancy. The best treatment is thermical. That is temperature of 18°C for 16 h and 26 C for 8 h to achieve seed germination (Nassar and Teixeira 1983). Seedlings ensuing from sexual seed are normally weaker than those arise of cuttings. This is logical due to genetic heterozygosis structure of cuttings, while the sexual seed are homozygous for recessive and prejudicial genes.

For about a month and a half approximately after sprouting, the plant shoot expands and its depth increases. Vegetative growth and leaf area approaches a maximum within five months (Williams and Gazalli 1969). Flowering of the plant depends on the variety and on the environmental conditions, but once initiated, it continues periodically for the rest of the plant life. Root enlarges, with deposits of starch by he eighth week after planting. Thickening commences at the proximal part of the root and progresses towards the distal part. The thickening of roots stops after 7–9 months in most of cultivars (Beck 1986).

Cultivars Classification

Cassava is a single species, *Manihot esculenta* Crantz synonymous with *Manihot utilissima* Pohl Nassar (1978a). It belongs to the family Euphorbiaceae. It has a sporophytic chromosome number $2n = 36$. Some aneuploids were reported for certain cultivars (Nassar 1978b; Nassar et al. 1996a, b) but this is not common. Polyploids are rare though. For some authors (Magoon et al. 1966) cassava could be an allotetraploid.

Cassava cultivars have been classified according to morphology (e.g., leaf shape and size, plant height, stem color, petiole length and color, inflorescence and flower color, tuber shape and color, earliness, and content of cyanogenic glycoside in the roots (Rogers 1963, 1965).

Cyanogenic glycoside has been used to place cassava cultivars into two major groups: the bitter cultivars, in which the cyanogenic glycoside is distributed throughout the root and is at a high level, more than 100 mg/kg; and the sweet varieties, in which the glycoside is confined mainly to the peel and is at a lower level. The flesh of sweet varieties is therefore relatively free of glycoside, although it always contains some (Brujin 1971). In general, sweet cassavas tend to have a short growing season; their tubers mature in 6–9 months, and deteriorate rapidly if not harvested soon after maturity. The bitter cassava cultivars, on the other hand require 12–18 months to mature, and will not deteriorate greatly if left unharvested for several months (Bolhuis 1966), see Fig. 1.

Wild relatives

Wild relatives of cassava are perennial and vary in growth pattern from nearly acaulescent subshrubs to small trees. Decumbent subshrubs, semiherbaceous subshrubs, shrubs, and small trees are found in the genus (Rogers 1963, Rogers and Appan 1973, Nassar 1986). The branching pattern is typically dichotomous or trichotomous, having at the point of branching a terminal inflorescence. Bark of the woody species is generally smooth. Many of the species are lacticiferous, and some species particularly *M. glaziovii* Muell.-Arg. (Ceara rubber, Fig. 2) are still cultivated in some countries (Brazil and Nigeria) for rubber production (Rogers 1963, 1965). This species was used by Storey and Nichols in the 1930s in Tanzania (Formerly Tanganyka) to transfer resistance to mosaic disease (Storey and Nichols 1938). Populations of this species now grow near IITA HQ at Lagos, Nigeria. Many species such as group *tripartita* have their stems adapted to marked dry periods; die back to a root crown regularly and shed their leaves during the dry season. Species are found on limestone derived and well drained soils. All of the species are damaged by frost with exception of very few such as *M. grahamii* and *M. neusana* whose native distribution in regions with occasional frost. All species are monoecious, some few are dioecious which make them obligate cross pollinated. In many species, they are protogeneous, i.e., having pistillate flowers open before staminate flowers of the same inflorescence. Pollination is by insects to whose bodies the sticky pollen adheres. This cross pollination phenomena leads to formation of

Fig. 1 A multiembryonic ovule

Fig. 2 *Manihot glaziovii* Muell.-Arg.

extremely heterozygous gene pools (Nassar and Freitas 1997). Being polyploid species, partially apomictic, and having week barriers in addition to the allogamous nature, the plant suffered the rapid speciation and formation of large number of species (Nassar 1999, 2000a, b).

All species of the genus *Manihot* Adans. are native to South America (particularly Brazil). The only species found in other tropical regions of the world are those that have been introduced since Columbus voyages to the American continent. The species of *Manihot* Adans. are all rather sporadic in their distribution and rarely become dominant of the local vegetation. Majority of these species are found in relatively dry regions, and only a few are found in rain forest regions. Their typical habit is openings in the forest as the case of *M. anomala* Pohl. So they are typically heliophiles growing only in the absence of shading. Many of them such as *M. pohlii* Warwa, *M. zehntneri* Ule and *M. grahami* Hooker are weedy types capable of invading recently disturbed areas. Many *Manihot* Adans. species are found on limestone derived and well drained soils. All of the species are damaged by frost with exception of very few such as *M. grahami* Hooker and *M. neusana* Nassar whose native distribution in regions with occasional frost.

Manipulation of its genetic resources

Wild *Manihot* Adans. species have been used by this author as a source of useful characters, the most notable achievement was the production of high protein content which reached level of 4% of peeld roots weight, i.e., double of protein content in common cassava, combined by low HCN content of 90 mg per kg (Nassar and Dorea 1982). The wild parent was *M. oligantha* Pax (Nassar 1978b, 1978c, Fig. 3). Recently, the same author has transferred successfully genes of apomixis from the wild species *M. neusana* Nassar (Nassar et al. 1998a, b; 2000; Nassar 2000b). Probably the most important of the utilization of wild cassavas is the discovery of a durable resistance to mealy bug in *M. glaziovii* Muell.-Arg. and the transference of its genes to common cassava through traditional interspecific hybridization (Nassar 1997, 2004). This interspecific

Fig. 3 *Manihot oligantha* Pax

hybrid could be polyploidized and having its fertility restored (Nassar 2004). This material may play an important role in alleviating all Africa from the danger of mealy bug should the system of biological control for combating this pest may broke down due to its artificial structure. Signs of mealy bug attack in the last years in very small areas in Zaire were reported (R. Ortiz, personal communication 2004). Apparently introducing a durable resistance from a relative species may be the solution.

Cassava genetic diversity does exist due to two reasons: first occurrence of occasional sexual propagation, and second infusion between types of cassava that have similar phenotypes, but are of different genetic constitution. On the other hand genetic diversity at intervarietal level may diminish because of genetic drift, for example, cassava plant produces limited number of cuttings. Certain plants (genotype) may be eliminated as their cuttings not being replanted for one reason or another.

This author began a program supported by the Canada International Development Research Center (IDRC) aiming to utilize wild cassava for improvement of cultivated cassava (Nassar 1989). Wild *Manihot* Adans. species were collected from South America and Mexico, evaluated thoroughly and hybridized with cultigens to incorporate their useful genes. Cultivars with high protein content, apomixis, tolerance to drought, resistance to bacterial blight high yield were bred (Nassar 1980; 1991, 1994, 1997, 1999).

In the decade 1990s, IITA scientists successfully bred cassava cultivars with a durable resistance to diseases such as Bacteria blight and cassava mosaic (CMD)(14). For this achievement they used hybrids of cassava with wild relatives, some of which were supplied by this author (Ortiz, 2004). IITA deployment of this material in Uganda was a great success. IITA produced millions of cassava plantlets and cuttings and delivered them into the hands of Nigerian farmers. The improved plants not only resisted diseases, but also slowed its spread in non-resistant cultivars. It is estimated that more than 4 millions hectares are planted now in Nigeria with these cultivars resistant to Bacteria Blight and CMD (Dixon et al. 2003).

Potentiality of genetic resources

In Brazil, cassava is place of origin, its domestication through thousands of years has led to evolving of extremely invaluable types that are rich in different kinds of carotinoids. Screening some indigenous clones enabled this author and coworker (Nassar et al. 2005) to select clones with high B-carotene content (Fig. 4), as well as rich in lycopene cultivars (Fig. 5). This nutritive value was accompanied by an excellent palatability and taste. This author has propagated them and distributed to small farmers in the district federal and adjacent states. Moreover, has stepped towards promoting a company to educate these farmers and alert them to the nutritive value of these clones.

Fig. 4 Cooked root of the indigenous yellow cassava cultivar, UnB 400

Fig. 5 Cooked root of the indigenous red cassava cultivar, UnB 500

By the use wild species, *M. oligantha* Pax as a source of high protein, additional nutritive gains could be obtained. The produced interspecific hybrid had its leaves very high in Lutein that it reached 9,000 mg/kg compared to 700 mg/kg in common cultivars (Nassar et al. 2005).

High productive clones have been obtained through interspecific hybridization with wild species (Fig. 6). The use of certain wild species, namely *M. glaziovii* Muell.-Arg., *M. pseudoglaziovii* Pax et Hoffmann (Fig. 7) and *M. caerulescens* Pohl. resulted in increasing notably production of the roots (Fig. 8). The produced hybrids reached 3–4 times productivity of common varieties. In certain cases this vigor of hybrid is extended to the vegetative growth (Fig. 9).

Prospects of future plant breeding

Cassava is a monocious plant but selfing does occur due to monoclonal cultivation system. It seems that heterotic effect is predominant in root production. For this reason, breeding by combining ability showed high success when used, enabling India to triplicate its productivity during thirty years jumping from 9 t/ha in the 1960s to 26 t/ha in 2000 while other centers for cassava stationed in the same level of productivity during the same period. Productivity in South America was 14.5 in the 1960 and dropped to 12.5 during the following 30 years.

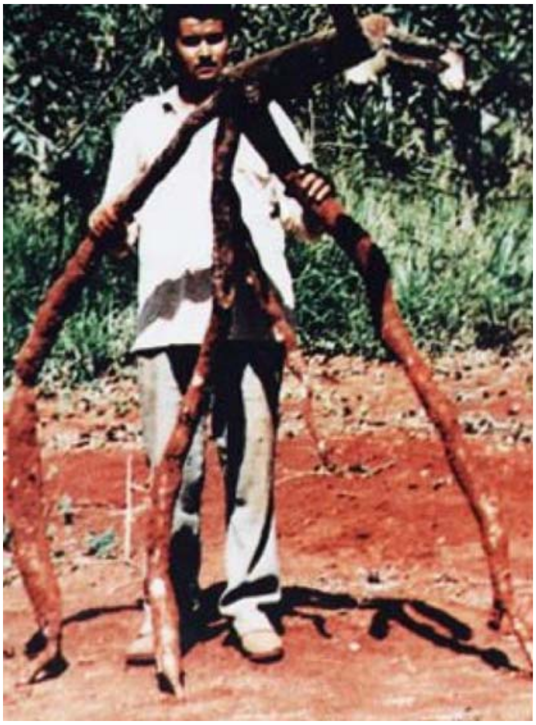

Fig. 6 Root of cassava interspecific hybrid with *Manihot pseudoglaziovii* Muell.-Arg.

Fig. 8 Root of progeny of cassava interspecific hybrid with *Manihot caerulescens* Pohl

Fig. 7 *Manihot pseudoglaziovii* Muell.-Arg. in natural habitat

Fig. 9 Cassava interspecific hybrid with *Manihot neusana* Nassar

Mealy bug is the most important danger threatening cassava in Nigeria and Zaire. Biological control proved effective in the last 20 years, but some cases of its virulence attack were recorded in the last three years

The breakdown of this introduced artificial ecosystem may happen. The most durable mean is to breed cassava cultivars resistant to this pest. *M. glaziovii* Muell.-Arg. proved an excellent resource. It is also very resistant to bacteria blight and Mosaic. This author has bred polyploidized interspecific hybrids between this species and cassava, restoring its fertility and facilitating its utilization. The ideal method to control mealy bug is to breed cultivars from this material. The author has made it disponible for IITA researchers.

Wild *Manihot* Adans. are sources for valuable characters for improving the crop. They were neglected for a long time. However, a successful case was its manipulation by IITA Scientists led by S. K. Hahn (1980) in the decade 1980 successfully utilized a material provided by this researcher to produce cultivars resistant to bacteria blight and mosaic. These cultivars are cultivated now in more than 4 millions hectares in Nigeria. Further hybridization should be done, since present cultivars will loose their resistence by pathogen mutations during some decades.

Apomixis offers a very valuable mean to protect the crop against contamination and permit maintaining heterosis effect. It was transferred from the wild species successfully by this author to the cultigen (Nassar 1995, 2001, 2004). However, its level should be increased, to meets practical use by farmers.

Screening indigenous clones has revealed some of them to be very rich in carotinoids (B-carotene, and lycopene) combined by excellent palatability and taste. These clones were optimized through process of domestication along thousands of years. They may play an important role in alleviating hunger for poor people in the tropics. However, there is a need to educate and alert people about their nutritive value.

Acknowledgements This work is being supported by the Brazilian National council for Scientific Development (CNPq), Brasilia. The above-mentioned living collection was established at the Universidade de Brasilia, with the help of the Canadian International Development Research Center (IDRC), Ottawa in the years 1976-1982 to whom this author is grateful.

References

Anonymous (1989) Central tuber crops research institute annual report. Thruvandrum, 1989, 86 pp. 2

Beck BD (1986) Cassava trials on Moor plantation. Rep. Dept. Agric. Res. Nigeria, 1958–1959

Beck BC (1986) Cassava trials on moor plantation. Rep. Dept. Agric. Res. Nigeria, 1958–1959

Bolhuis GG (1966) Influence of length of the illumination period on root formation in cassava. Neth J Agric Sci 14:151–262

Bruijn GH (1971) A study on cyanogenetic character of cassava (*Manihot esculenta* Crantz), Mededelingen Landbouwhogesschool Wangeningen, 140 pp

Coursey DG, Hybnes PH (1970) Root crops and their potential as food in the tropics. World crops 22(5):261–265

Dixon AGOA, Brandyop R, Ortiz R (2003) Cassava from poor farmers crop to Pacesetters of African Rural Development. Chronica Horticulturae 43 3–69 FAO Yearbook 2002

FAO Yearbook, 2003, Rome

Lancaster PA, Ingram JS, Lim MY, Coursey DG (1982) Traditional cassava based foods: survey of processing techniques. Econ Bot 36(1):12–45

Magoon ML, Joss JS, Appan SG (1966) Cytomorphology of interspecfic hybrid between cassava and ceara rubber. Chromosome Information Service (Japan) pp 8–10

Nassar NMA (1978a) Conservation of the genetic resouces of cassava (*Manihot esculenta* Crantz): determination of wild species localites with emphasis on probable origin. Econ Bot 32:311–320

Nassar NMA (1978b) Genetic resouces of cassava: chromosome behaviour in some *Manihot* species. Ind J Genet. 38(1):135–137

Nassar NMA (1978c) Hydrocyanic acid content in some wild *Manihot* (cassava) species. Can J Plant Sci 58:577–578

Nassar NMA (1986) Genetic variation of wild *Manihot* species native to Brazil and its potential for cassava improvement. Field Crops Res 13:177–184

Nassar NMA (1989) Broadening the genetic base of cassava, *Manihot esculenta* Crantz by interespecific hybridization. Can J Plant Sci 69:1071–1073

Nassar NMA (1991) Production of triploid cassava, *Manihot esculenta* Crantz by hybrid diploid gametes. Field Crops Res 13:173–182

Nassar NMA (1995) Development and selection for apomixis in cassava *Manihot esculenta* Crantz. Can J Plant Sci 4:857–858

Nassar NMA (1997) Development of cassava interespecific hybrids for savana (cerrado) conditions. J Root Crops 22:9–17

Nassar NMA (1999) Cassava, *Manihot esculenta* Crantz genetic resources: their collection, evaluation and manipulation. Adv Agronomy 69:179–230

Nassar NMA (2000a) Wild Cassava, *Manihot* spp.: biology and potentialities for genetic improvement. Genet Mol Biol 23:201–212

Nassar NMA (2000b) Cytogenetics and Evolution of Cassava (*Manihot esculenta* Crantz). Genet Mol Biol 23:41003–41014

Nassar NMA (2001) The nature of apomixis in cassava (*Manihot esculenta* Crantz). Hereditas 134:185–187

Nassar NMA (2004) Polyploidy, Chimera and fertility of interspecific cassava, *Manihot esculenta* Crantz. Indian J Genet Plant Breed 62:132–133

Nassar NMA, Costa CP (1978) Tuber formation and protein content in some wild cassava species native to Brazil. Experientia (Basel) 33:1304–1306

Nassar NMA, Dorea G (1982) Protein contents of cassava cultivars and its hybrid with *Manihot* species. Turrialba 32(4):429–432

Nassar NMA, Teixeira (1983) Seed germination of wild cassava species (*Manihot* spp.). A quebra de barreira da semente das espécies selvagens da mandioca. *Manihot* spp. (In Portuguese). Ciência e Cultura 35(5)630–632

Nassar NMA, Freitas M (1997) Prospects of polyploidizing cassava. *Manihot esculenta* Crantz, by unreduced microspores. Plant Breed 116:195–197

Nassar NMA, Nassar Hala NM, Vieira C, Carvalho A (1996a) Induction of a productive aneuploid in cassava, *Manihot esculenta* Crantz. Braz J Genet 19: 123–125

Nassar NMA, Carvalho A, Vieira C (1996b) Overcoming barries between cassava *Manihot esculenta* Crantz and wild relative. *M. pohiil* Warwa. Braz J Genet 19: 617–620

Nassar NMA, Vieira C, Grattapaglia D (1998a) Molecular and embryonic evidence of apomix in cassava interspecific hybrids (*Manihot* spp.). Can J Plant Sci 78:348–352

Nassar NMA, Vieira C, Grattapaglia D (1998b) Evidence of apomixis in cassava (*Manihot esculenta* Crantz). Genet Mol Biol 21:527–530

Nassar NMA, Santos E, David SRO (2000) The transference of apomixis genes from *Manihot neusana* Nassar to cassava, *M. esculenta* Crantz. Hereditas 132: 167–170

Nassar NMA, Vizzotto CA, da Silva HL, Schwartz CA, Pres Junior OR (2005) Geneconserve www.geneconserve.pro.br articles , issue no. p :267–283

Ortiz R (2004) Acknowledgement : www.geneconserve.pro.br/iita2.gif

Rogers DJ (1963) Studies of *Manihot esculenta* Crantz (Cassava) and related species, Bull Torrey Bot 90:43–54

Rogers DJ (1965) Some botanical and ethnological considerations of *Manihot esculenta* Crantz. Econ Bot 19:369–377

Rogers DJ, Appan SG (1973) *Manihot, Manihotoides* (Euphorbiaceae) Hafner Press, New York, 272

Storey HH, Nichols RFW (1938) Studies on the mosaic disease of cassava. Ann Appl Biol 25:790–806

Williams CN, Gazhali SM (1969) Growth and productivity of tapioca (*Manihot utilissima*) 1, Leaf characteristics and yield. Exp Agric 5:183–194