Yam breeding

R. Asiedu, H. Mignouna, B. Odu, and J.d'A. Hughes

International Institute of Tropical Agriculture PMB 5320, Oyo Road, Ibadan, Nigeria

Abstract

Yams (*Dioscorea* species of family Dioscoreaceae) are important for food, income, and sociocultural activities especially in West and Central Africa and account for about 93% of the world's annual production of 38 million tonnes. Breeding of yams is focused primarily on the two dominant species, *D. rotundata* Poir. and *D. alata* L., and it is carried out within the context of improving yam-based systems. Constraints to productivity of cultivation and opportunities for improvement are identified through reviews of existing information, new surveys, or stakeholders' meetings. Hence the principal objectives for breeding include high and stable tuber yield, resistance to pests (e.g., nematodes) and diseases (e.g., viruses, anthracnose), as well as tuber characteristics (shape, food quality) desired by consumers. Viruses are of particular concern in yam research and development because they impose a double limitation in the form of reduced field performance as well as restricted international exchange of germplasm. Of the several viruses infecting yams, the most commonly occurring in West Africa is the *Yam mosaic virus* (YMV), genus *Potyvirus*. Field and screenhouse evaluation of *Dioscorea* germplasm held at IITA has resulted in the identification of high levels of resistance to the virus in *Dioscorea* landrace cultivars. The inheritance of resistance to the virus in *D. rotundata* has been established through positive screening of populations at the seminal and clonal stages. These sources form the basis for population improvement towards the development of new yam varieties with higher levels of virus resistance.

Résumé

Les ignames (espèces *Dioscorea* de la famille des Dioscoreacées) tiennent un rôle important dans l'alimentation, les activités socio-culturelles, et comme source de revenus surtout en Afrique de l'Ouest et centrale qui contribuent jusqu'à 93% des 38 millions de tonnes d'ignames produites chaque année dans le monde. La sélection des ignames est principalement focalisée sur les deux espèces majeures, à savoir *D. rotundata* Poir. et *D. alata* L. Elle se déroule dans le cadre de la recherche sur l'amélioration des systèmes à base d'igname. Les contraintes à la production, et les opportunités en

matière d'amélioration sont identifiées à travers la recherche documentaire, les nouvelles enquêtes et les réunions des parties prenantes. Ainsi, les objectifs principaux de la sélection englobent des rendements en tubercules plus élevés et stables, la résistance aux ravageurs (ex. nématodes) et aux maladies (virus, anthracnose), de même que les caractéristiques des tubercules (forme, qualité alimentaire) recherchées par les consommateurs. Les virus constituent une préoccupation particulière en matière de recherche et développement sur l'igname : ils limitent doublement la production en affaiblissant le comportement au champ et freinent l'échange du matériel végétal au-delà des frontières. Parmi les nombreux virus qui infectent les ignames, le plus couramment rencontré en Afrique de l'Ouest est le virus de la mosaïque de l'igname (YMV) du genre *Potyvirus*. L'évaluation en abri grillagé et en plein champ du matériel végétal de *Dioscorea* effectuée à l'IITA a permis d'identifier de hauts niveaux de résistance au virus dans les cultivars locaux de *Dioscorea*. Le transfert de la résistance au virus dans *D. rotundata* a été établi à l'aide d'un criblage positif des populations aux stades séminal et clonal. Ces sources fournissent une base aux programmes d'amélioration des populations en vue de la création de nouvelles variétés d'igname dotées de niveaux élevés de résistance au virus.

Yams for food and income

The most important zone for the cultivation and use of yams (*Dioscorea* species) stretches from Côte d'Ivoire through Ghana, Togo, Bénin, Nigeria, Cameroon, Gabon, Central African Republic, and the western part of the Democratic Republic of Congo. This subregion (West and Central Africa) accounts for about 93% of the world's annual yam production of 38 million tonnes (FAO 2000). Nigeria produces about 70% of the world total. The crop is also important in the Caribbean and the South Pacific Islands.

Yams constitute an important source of food and income and play a major role in sociocultural life for a wide range of smallholder households. They bring flexibility to the annual cycle of food availability through several species and cultivars, broad agro-ecological adaptation, early season drought tolerance, and diverse maturity periods. At harvest, 10 to 30% of yam tubers are kept for planting during the next growing season. The remainder is used as food, exported, or lost during storage (5–40%). The tubers have organoleptic qualities that make them the preferred carbohydrate food where yams are grown contributing up to 350 dietary calories per person each day for millions of people in the major producing countries. In a recent urban food demand study in three cities (Kano, Kaduna, and Abuja) in the north of Nigeria, the proportions of households purchasing yams weekly were 62% in Kano, 88% in Kaduna, and 97% in Abuja (IITA 2000). Yam tubers may be eaten with sauce directly after boiling, frying in oil, or roasting. They may also be cooked into pottage with added protein sources and oils. One very popular method of preparation in coastal West Africa is the boiling and pounding of the tuber pieces into a thick dough (called *fufu* or pounded yam) that is consumed with soup. Another popular dough (called *amala* in Nigeria and *konkonte* in Ghana) is prepared in hot water from flour derived from dried yam tubers. A few commercial products based on dry flakes or flours from the tuber are produced in Nigeria, Ghana, and Côte d'Ivoire for export and sale in urban areas. The flakes are produced from fresh tubers by peeling, dicing, sulphite bathing, cooking, mashing, drying, and flaking followed by packaging.

The most important food species are *D. rotundata* (white Guinea yam) indigenous to West Africa and *D. alata* (water yam) introduced from Asia to Africa during the 16th century. *D. rotundata* is the most cultivated and consumed of the genus and also has the highest market value owing to the superior suitability of its tubers to the preferred food use for the crop in West Africa. However, *D. alata* is superior to it in yield potential (especially under low to average soil fertility), ease of propagation (through production of bulbils and reliability of sprouting), early vigor for weed suppression, and storability of tubers.

Challenges to cultivation

Yam cultivation requires large amounts of labor for mounding, staking (especially in the forest zone), weeding and harvesting. As a result, labor input per hectare is roughly twice that for cassava and four times that for maize. The best land is often allocated to yams since the crop requires deep, fertile, well-drained soils. Cost of planting material is also high, as about one quarter of the total weight of each year's harvest is used to plant the next year's crop. The potential for increased production of yams seems highest in the savanna zone where higher intensity of solar radiation makes staking less important, and there are fewer limitations on the availability of fertile land.

With a benefit:cost ratio of about 3:1, yam production is profitable (IITA 1999). However, the productivity of yam cultivation has been under intense pressure from reduction in soil fertility and pest buildup due to shortening fallow periods, and increasing cost of production. Nematodes (*Scutellonema bradys* and *Meloidogyne* spp.), often interacting with fungal (e.g., *Botryodiplodia*, *Fusarium*) and bacterial (e.g., *Erwinia* sp.) pathogens, attack tubers of susceptible varieties in the field and continue their damage during storage, leading to loss of food quality and quantity as well as of planting materials. Yam production and marketing are also affected by a range of insect pests on the foliage, e.g., the leaf beetle (*Crioceris livida*) and the tuber, e.g., termites (*Amitermes* sp.), tuber moth (*Euzopherodes vapidella*), mealybug (*Planococcus* spp., *Phenacoccus* spp.), scale insect (*Aspidiella hartii*), and tuber beetles (*Heteroligus* spp., *Prionorcytes* spp.). Anthracnose disease (caused by *Colletotrichum gloeosporioides*) remains a major threat to the cultivation of *D. alata* in all yam producing areas (Akem and Asiedu 1994). Yam cultivation is also severely constrained by the accumulation of virus infections, in particular by *Yam mosaic* virus (YMV) genus *Potyvirus*.

Viruses infecting *Dioscorea* species

Of the many viruses that infect *Dioscorea* species, six are known to infect the yams cultivated in West Africa. These are *Yam mosaic virus* (YMV) genus *Potyvirus, Dioscorea alata virus* (DAV) genus *Potyvirus*, *Dioscorea dumetorum virus* (DdV) genus *Potyvirus, Dioscorea alata bacilliform virus* (DaBV) genus *Badnavirus*, *Cucumber mosaic virus* (CMV) genus *Cucumovirus*, and *Dioscorea mottle virus* (DMoV) genus *Comovirus.*

In Burkina Faso, 10% infection of yams in the southwest and 100% in the center (a zone dominated by the susceptible cultivar of *D. rotundata*, Pilimpikou) have been reported (Goudou-Urbino et al. 1993). In Nigeria, Hughes et al. (1997) found 46% incidence of DAV in *D. rotundata* and 69% in *D. alata*; 53% incidence of YMV in *D. rotundata* and 29% in *D. alata*; and 15% incidence of DMoV (genus *Comovirus*) in *D. alata*. Olatunde (1999) found less than 1% incidence of DAV in *D. alata* in major yam growing areas of Ghana. He also found 28–70% incidence of YMV (genus *Potyvirus)* in *D. rotundata* in those areas.

Thouvenel and Dumont (1990) established 25% yield advantage of healthy plants of *D. alata* cv. Florido over YMV-infected plants in Côte d'Ivoire. Similarly Mantell and Haque (1979) observed 29–41% yield advantage of healthy plants of *D. alata* cv. White Lisbon. Indeed, the expansion in cultivation of *D. trifida* in the Caribbean is impeded by YMV.

An expanding range of diagnostics facilitates studies on the distribution and impact of yam viruses on yam cultivation. These include enzyme-linked immunosorbent assays (ELISA) using triple antibody sandwich (TAS) for YMV or protein A sandwich (PAS) for DAV, DLV, DaBV, DDV, CMV, and DbBV; electron microscopy; herbaceous indicator plants; vector transmission studies; and immunocapture reverse-transcriptase -PCR (IC-RT-PCR) for YMV and DAV.

Use of planting materials (seed tubers) obtained from healthy plants for yam cultivation is a major way of limiting the incidence and severity of virus infection. Gaps remain in the knowledge of vector transmission in the field and vector control on farmers' fields may not be practicable. Host-plant resistance in varieties with good agronomic and quality attributes would be much more effective, especially in combination with the use of "clean" seed tubers. With reported variability among isolates of the virus, the deployment of different genes and different mechanisms of resistance would be ideal for ensuring durability of resistance.

Field and screenhouse evaluation of *Dioscorea* germplasm at IITA has resulted in the identification of high levels of resistance to *Yam mosaic virus* (YMV), genus *Potyvirus* in five accessions (four landrace cultivars and one breeder's line) of *D. rotundata* and two of *D. alata* (Odu 2002). The genetic basis of resistance in *D. rotundata* to a Nigerian isolate of YMV was investigated in three tetraploid *D. rotundata* genotypes: TDr 93-1, TDr 93-2, and TDr 89/01444 (Mignouna et al. 2001). Segregation ratios indicated that a single dominant gene in a simplex condition governs the resistance in TDr 89/01444, while the resistance in TDr 93-2 is associated with the presence of a major recessive gene in duplex configuration. A single dominant gene, possibly with modifiers, was established as controlling resistance in TDr 93-1.

Genetic improvement

The International Institute of Tropical Agriculture (IITA) has a global mandate for research on yams within the Consultative Group on International Agricultural Research (CGIAR). The Institute's yam researchers develop and disseminate improved technologies targeted at increased productivity of yam-based systems in partnership with national programs and advanced laboratories. Specifics of this include strategies for integrated control of pests and diseases in the field and during storage, soil and crop management suited to intensified cultivation of yams; reduced labor input in yam-based systems, and manipulation of tuber dormancy to increase efficiency in propagation and flexibility in crop cycles. Expanded utilization opportunities through processing into various products and improvements in marketing channels would influence productivity and bring the benefits from the crop to a broader range of consumers. New and more productive varieties of yams are needed to increase and sustain the productivity of yam cultivation in the face of a deteriorating resource base. Farmers have been relying on natural variation for their selection of suitable varieties to cope with the situation but the pace of this is not compatible with that of the changes in challenges in the physical and socioeconomic environment. Breeding and selection of yams are carried out at IITA in the context of improving yam-based systems and with primary focus on *D. rotundata* and *D. alata*. The attributes desired in a good yam cultivar vary according to region and species involved. Hence, constraints to productivity of cultivation, and opportunities for improvement are identified through reviews of existing information, new surveys, and/or stakeholders' meetings. Generally, the principal objectives for most yam improvement programs include high and stable yield of marketable tubers, good tuber quality (e.g., in terms of dry matter content, cooking quality/texture, taste, dormancy period, rate of enzymatic browning), resistance to biotic stresses in the field and during postharvest storage, tolerance to abiotic stress (e.g., drought and low soil fertility), and suitability to prevalent cropping systems (e.g., plant architecture, vigor, and maturity period).

The breeding scheme begins with characterization and evaluation of germplasm received from farmers, NARS, and IITA's collection for field performance, tuber quality, morphology, and ploidy status leading to the selection of parents for hybridization that have desirable traits relevant to objectives of the program. Botanic seeds are generated through biparental crosses and open pollination among selected clones planted in isolation from the main yam fields. Additional seeds are obtained through natural hybridization in clonal trials and on farmers' fields. Seedlings from these seeds are evaluated in nurseries from which selections go through a series of clonal trials towards the selection of superior genotypes.

The clonal trials start with unreplicated (observational) trials (clonal evaluation), with variable numbers of clones and stands per clone. At the preliminary (PYT), advanced (AYT), and uniform yield trial (UYT) stages, a randomized complete block design has been used with 3–6 replications. By the fifth year of evaluation, the materials can be subjected to a series of tests for their cooking and processing attributes in addition to evaluation for yield and reaction to pests and diseases. Owing to the slow multiplication rate of yams, it is necessary to make a special effort after the first advanced yield trial in the sixth year to multiply planting materials before extensive multilocational testing of selected materials. Simultaneously, the Tissue Culture Unit at IITA, in collaboration with the Plant Quarantine Service in Nigeria, carries out the process of virus elimination, micropropagation, and certification. In addition to a broad-based population targeting the Guinea savanna zone of West Africa, specific populations, e.g., resistance to *Yam mosaic virus* (YMV), genus *Potyvirus* in *D. rotundata*, are being improved through recurrent selection.

Partnerships

Several high-yielding andpest/disease-resistant genotypes with good tuber characteristics have been selected and disseminated to partners in the national yam programs. The capacity of national agricultural research systems (NARS) in West Africa for yam research and development has improved over the past decade. There are now recognized yam programs in the major yam producing countries of the subregion. Improved support, such as through the IFAD bilateral loan programs on root crops in Ghana, Bénin, and Nigeria, provides a boost to the development of yams. Subregional networking, collaborative research, and local selection from improved germplasm provided by IITA have increased. For instance, the West African Seed Development Unit (WASDU) initiated multinational, farmer-managed, on-farm adaptive trials on yams in West Africa in 1999 based on IITA-derived varieties that had previously been tested by NARS in on-station trials. These are conducted in Guinea, Togo, Bénin, and Tchad. Colleagues in Burkina Faso are evaluating 59 IITA-derived genotypes of *D. rotundata* towards selection for farmer-participatory trials. Several other IITA-derived varieties of yams are evaluated on-station and on-farm annually. For example, 234 clones of *D. rotundata* were evaluated in various trials in Bénin, 166 in Togo, 169 in Ghana, and 80 in Côte d'Ivoire in 2000. From such evaluations, three IITA-derived varieties were formally released in April 2001 by the National Root Crops Research Institute (NRCRI), Nigeria. NRCRI is also testing over 100 IITA-derived varieties in six yam growing states of Nigeria in a farmer-participatory selection scheme.

Challenges

The main obstacles encountered in sexual hybridization of yams in the past have included sparse flowering, poor synchronization of male and female flowering phases, and lack of efficient pollination mechanisms. Advances have been made in studies of reproductive biology of yams especially at the Central Tuber Crops Research Institute (CTCRI), Trivandrum, India, and IITA, Ibadan, Nigeria (Akoroda 1985; Abraham and Nair 1990). Many parental genotypes, especially of *D. rotundata*, have been identified over the years that combine good agronomic attributes with reliable flowering and high fertility. Techniques for manipulation of flowering periods to enhance sychronization and extend pollination periods have been established. Anthesis times, periods of pollen viability and stigma receptivity have also been determined for the relevant species. Moreover, storage of pollen from *D. rotundata* in a viable condition at 0% relative humidity and –5 °C for up to one year has been demonstrated (Akoroda 1983). This has the potential to iron out the nonoverlapping of male and female flowering phases. In spite of the foregoing, further work is in progress to develop protocols for inducing flowering in nonflowering but agronomically desirable varieties (especially of *D. alata*).

Other technical challenges to breeding and selection of yams include the long breeding cycle, very low multiplication ratio of propagules, and the existence of a juvenile phase during the seminal and early clonal stages of selection. Moreover, the available methods for evaluating important traits such as tuber quality (based on sensory evaluation of food products) cannot be applied at early stages of the selection cycle when tubers per clone are few and small and the populations are large. The challenges in screening of yam genotypes for reaction to viruses include the multiplicity of viruses and symptom types, mixed virus infections, the confounding of infection symptoms with those of nutritional disorders, the high genetic diversity of YMV, and the absence of methods for rapid and reliable field diagnosis.

It has been established that the viability of yam seeds deteriorates during storage at room temperature and germination can reach a low of 30–40% one year after harvest (IITA 1975). Management of seedling nurseries poses a good challenge in horticultural practice. The seedlings are delicate and are subject to a number of fungal diseases, some of which may not have relevance during the clonal phases of propagation. Presowing seed disinfectants are known to affect the percentage germination of seeds of *D. rotundata* (IITA 1975). Studies showed that the most effective way to disinfect yam seeds without significantly affecting germination is to soak for 20 minutes in 10% w/v calcium hypochlorite.

The early clonal (observational) trials are constrained by the low multiplication ratio of the tubers leading to a long period before multilocational yield trials can be established. As yams are a vegetatively propagated crop, the selection scheme involves repeated evaluation of clones selected from a seedling nursery or the germplasm collection over several years in clonal trials ending with on-farm testing. For yams, there is the natural break in the evaluation cycle each year due to dormancy in the tuber after harvest. A storage period of up to four months of propagules is quite normal for most yam selection programs before the subsequent season. Severe losses are often incurred at this stage. Some of these losses are advantageous to the selection process as materials that are most susceptible to storage pests and pathogens are thus weeded out. Nonetheless, there are often proportions of the losses that most researchers would have liked to carry to the next season. Materials for genetic studies are particularly crucial in this category. It is therefore imperative for yam research programs to ensure good facilities for tuber storage at an appropriate location that would offer some measure of flexibility and security.

Molecular tools

A genetic map of *D. rotundata* based on molecular markers has been developed. (Mignouna et al. forthcoming) A region on linkage group five of the female genome of *D. rotundata* was identified that has a major effect on resistance to the virus. Two random amplified polymorphic DNA (RAPD) markers linked in coupling phase with Ymv-1, a locus that contributes to YMV resistance in TDr 89/01444, were identified. Both markers were mapped on the same linkage group: $OPW18_{850}$ (3.0 ± 0.5 centiMorgans [cM]) and $OPX15_{850}$ (2.0 ± 0.5 cM). Such tools, in combination with improved diagnostics, would be invaluable in improving methodologies for screening in the field where the confounding influences of plant nutrient disorders and the multiplicity of virus-induced symptom types pose constant challenges.

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