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TROPICAL ROOT CROPS: PRODUCTION AND USES IN AFRICA
ABSTRACT

A mixture of original research, updates on procedures, literature reviews, and survey reports, this document resulted from the second symposium of the International Society for Tropical Root Crops — Africa Branch, with 77 participants from 16 countries. The focus was cassava, yams, cocoyams, and sweet potatoes, from the perspectives of breeders, agronomists, soil specialists, plant pathologists, entomologists, nutritionists, food technologists, etc. Learning from past successes and failures, many of the researchers directed their efforts toward problems obstructing progress in reaching improved production and use of root crops and attempted to view, realistically, the context in which their results would be applied.

RÉSUMÉ

Résultats de recherches récentes, mises à jour sur les méthodes de recherche, revues de publications et rapports de sondages sont contenus dans ce document issu du Deuxième symposium de la Société internationale pour les plantes-racines tropicales — Direction Afrique, qui a réuni 77 participants de 16 pays. Des communications sur le manioc, le yam et la patate douce ont été présentées par des phytoselecteurs, des agronomes, des pédologues, des phytopathologistes, des entomologistes et des spécialistes de la nutrition et des aliments, entre autres. Tirant leçon de leurs succès et de leurs échecs, beaucoup de ces chercheurs ont dirigé leurs efforts vers la solution des problèmes qui entravent l’augmentation de la production et de la consommation des plantes-racines et ont tenté de considérer d’un œil réaliste le contexte qui sera celui de l’application de leurs recherches.

RESUMEN

Una mezcla de investigaciones originales, actualizaciones de procedimientos, reseñas de literatura e informes de encuestas, este documento es el resultado del segundo simposio de la Sociedad Internacional de Raíces Tropicales, Filial Africana, que contó con 77 participantes de 16 países. El simposio se centró en la yuca, el yam, el cocoyam y las batatas, desde la perspectiva de los fitomejoradores, los agrónomos, los especialistas en suelos, los patólogos vegetales, los entomólogos, los nutritionistas, los tecnólogos alimenticios, etc. A partir de los éxitos y fracasos anteriores, muchos de los investigadores encaminaron sus esfuerzos hacia los problemas que obstaculizan el avance para lograr una producción y un uso mejorados de las raíces y trataron de obtener una visión realista del contexto en que los resultados pueden ser aplicados.
TROPICAL ROOT CROPS:
PRODUCTION AND USES IN AFRICA

EDITORS: E.R. TERRY, E.V. DOKU, O.B. ARENE, AND N.M. MAHUNGU
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Production potentials of Major Tropical Root and Tuber Crops

E.V. Doku

In comparison with the temperate regions, the tropical environment has lower solar-radiation levels, shorter photoperiods, and, hence, a lower potential productivity. Productivity of cassava, yams, sweet potato, and cocoyams, the four most important tropical root and tuber crops, has other constraints as well: inadequate water supply (in arid areas with optimal solar-radiation levels); pests and diseases; long maturation; and difficult-to-harvest roots and tubers with poor keeping quality.

Research so far has been insufficient to break the numerous bottlenecks, although there is great promise from exploration, conservation, identification, evaluation, and breeding of germ plasm and some high-yielding, adaptive, pest- and disease-resistant varieties have already been developed for distribution throughout Africa. Although yields of the highest yielding varieties currently available are only about one-third to one-half of estimated potentials, recent research on the continent is rapidly amassing knowledge with a concomitant crop-improvement achievement in the following order of priority: cassava, sweet potato, yam, and cocoyam. By the end of the decade, yield levels of commercial varieties of the four crops should approach their potential.

Crop growth and production depend upon the interaction of a population of plants (the crop) and the environment (atmosphere and rhizosphere) in which the crop grows. Each environmental factor may impose a limitation on productivity, and, conversely, increased productivity may arise from a cultivar's ability to overcome the limitations imposed by a single factor or set of factors.

Most of the factors of the rhizosphere — e.g., soil-nutrient status, moisture levels, salinity, pH, physical condition, etc. — can be dealt with agronomically or genetically. The factors of the atmosphere, however, cannot be so easily altered, and plants must be developed to perform under prevailing atmospheric conditions. of which the most important is solar radiation. Van der Paaq (1956) considered that atmospheric factors like CO₂ and temperature do not contribute much to yield fluctuations, as these are determined more or less by other factors such as water supply and mineral nutrition.

Because of cloudiness and high humidity of the tropical atmosphere, daily solar-radiation levels fall in the range of 300–500 cal/cm² — only about 0.2–0.3 of the peak radiations (about 1.2 cal/cm²/minute) observed under the clear skies in desert environments in the tropical and subtropical regions where water is the limiting factor in crop production (Loomis and Rapoport 1977). Tropical environments are further limited by short days (10.5–13 h).

In contrast, at higher latitudes in the temperate zone, daily radiation totals of 500 cal/cm² are common during the long summer days, a combination that favours high biomass production. Compared with the temperate regions, therefore, the tropical environment sets a lower limit to productivity. Because of favourable temperatures year round, the tropical regions have an advantage in production of perennial crops and long-season crops such as cassava, yam, and cocoyam. However, the long maturation of such crops makes them inefficient, as yields per unit of land and time are bound to be low.

De Wit (1965) estimated that the gross daily production of dry matter under average conditions of cloud cover (half the sky) was potentially 275 carbohydrate equivalents/ha (i.e., 1.1 × 10⁶ cal/ha), whereas De Vries et al. (1967) estimated the net potential to be half that amount (5.5 × 10⁵ cal/ha). Use of improved varieties under conditions of good husbandry (Watson 1947) would result in yearly production levels of 140 t/ha for cassava and yam and 200 t/ha for sweet potato and cocoyam. The highest levels for these crops so far are only one-half or one-third of these yield estimates.

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YIELD DETERMINANTS

Only a fraction of a plant's total dry-matter production (biological yield) is represented by the economically useful product (i.e., the root or tuber). Crop yields have been shown to depend upon the photosynthetic capacity of the leaves (source): the capacity of the plant to translocate assimilates from the source to the grain, root, tuber, etc. (sink); and the capacity of the sink to attract, capture, and store assimilates in the desirable form.

The ability to transform a high fraction of biological yield into economic yield is, therefore, the key to the realization of yield potential. Under every atmospheric condition, foliage architecture and photosynthetic capacity are the principal factors that affect primary productivity (biological yield) (Loomis and Rapoport 1976). The nature of the foliage cover is important in determining the efficiency with which solar radiation is used in primary productivity (Loomis and Williams 1969), and leaf-area index (LAI) has generally been used as an index of photosynthetic capacity. Because of changes in LAI with stage of development of a crop, leaf-area duration (D), the integral of LAI over time, was suggested by Watson (1947) as a measure of the plant's ability to produce and maintain its leaf area and hence its opportunity for assimilation.

A number of workers, including Williams et al. (1965) and Shibles and Weber (1966), suggested that the time integral of percentage solar-energy interception is better than LAI and D as an index of photosynthetic capacity. Solar-energy interception has, however, not been used to any extent as a determinant of photosynthetic capacity of crops, and Chapman (1965), Enyi (1972a), and Ferguson (1977) have concluded that LAI and D are the most important physiological determinants of yield from root and tuber crops.

Genetic determinants of yield include efficient utilization of the resources of the rhizosphere, resistance to the numerous field and storage pests and diseases, shelf-life, etc. The degree to which genetic variability in these attributes can be exploited by breeders for the improvement of the crop is the yardstick by which to judge current production levels as well as prospects for the realization of the potential. The interrelationships between physiological determinants and yield are little researched, even though understanding them is the key to optimal efforts in genetic improvement. In other words, a breeder needs to know how the plant is interacting with the environment before he or she can efficiently improve on the plant's ability to cope. More work, therefore, needs to be done. Considerable work has, however, been done on the development of pest- and disease-resistant varieties with remarkable results.

PESTS, DISEASES, AND AGRONOMIC PROBLEMS

Work carried out at the International Institute of Tropical Agriculture (IITA) as well as in many countries has established firmly that pests and diseases constitute major constraints to the production of root and tuber crops in Africa. Accordingly, the bulk of IITA research is geared toward finding solutions to this problem, through the development of resistant varieties as well as suitable cultural techniques and other control measures.

Other serious constraints include weed competition: the long maturation of cassava, yam, and cocoyam; difficult-to-harvest roots and tubers of cassava and yams; and the rather short postharvest life of all root and tuber crops, cassava in particular.

RESEARCH HIGHLIGHTS AND ACHIEVEMENTS

CASSAVA

In studies of physiological determinants, Enyi (1972a) found that 75% of the variation in cassava yields could be attributed to differences in D. However, Holmes and Wilson (1977) found that, although high leaf production and retention were important determinants of both total dry-matter and root yields in six West Indian cassava cultivars, high root yield was not necessarily correlated with high rate of leaf production and retention. One of the cultivars, Maracas Black Stick, produced high yields and had a high harvest index (HI) despite low production of leaves. It was suggested, therefore, that HI should be used in screening cultivars for high yield. The need to understand source-sink relationship as an important character in crop selection is implicit from these results. Cassava flowers and fruits readily, and techniques for hybridization and breeding have been worked out (Hahn et al. 1979; Hahn 1982a). Therefore, determining the genetic bases for these physiological determinants should be easy and would facilitate further breeding work.

The low yields (about 7 t/ha in 12 months) of cassava in Africa can be attributed largely to
diseases and pests (Hahn et al. 1979, 1982a). The major diseases and the yield losses attributed to them are: cassava mosaic disease (CMD) 20–90%; cassava bacterial blight (CBB) up to 100%; grasshopper 60–80%; cassava green mite (CGM) up to 40%; and cassava mealybug (CMB) up to 100%.

Cassava is also liable to weed infestation, especially during the first 10–12 weeks, and Godfrey-Sam-Aggrey (1978) reported 20% yield loss if first weeding were delayed by more than 2 months. In extreme cases, yield losses are total. Soil temperature, moisture, and rooting depth also affect root yield (Hahn et al. 1979). Soil temperatures higher than 30°C at 5 cm below the surface occur frequently in the field; hence, yield reduction can be considerable.

In spite of the common observation that cassava is fairly drought-tolerant, significant yield reductions have been observed under drought conditions (Shanmugavelu et al. 1973). High soil temperatures strongly interact with moisture stress to reduce yields even further.

The IITA root and tuber program has screened several hundred clones for resistance to grasshopper, and some tolerant clones whose shoots and stems are not damaged have been selected for further work. One Manihot species from South America has also been identified as showing resistance to the mealybug, and a breeding program involving this resistant species will soon start. A biological control program in collaboration with the Commonwealth Institute of Biological Control (CIBC) is already under way, and parasites and predators have been released in Zaire. Preliminary observations indicate that the program will be successful. Chances of finding resistance to the green mite are also high, and already five tolerant clones have been observed in Tanzania. Pubescence and growth vigour are strongly associated with green-mite resistance.

Major success has been achieved in controlling CMD and CBB, with the breeding of resistant varieties, all of which yield well, have good consumer acceptance, and are low in HCN. IITA-bred varieties TMS 30572 and TMS 30555 have yielded more than 40 t/ha since 1973 without fertilizer and have shown adaptation over 26 Nigerian environments differing in soil, rainfall, and other climatic conditions. Both are moderately resistant to CBB and CMD, and their progeny have performed similarly well in Sierra Leone, Gabon, Zaire, Zanzibar, Seychelles, as well as in India (Hahn 1982a).

Two other new varieties TMS 30001 and TMS 30395 are very resistant to both CBB and CMD and give reasonable yields (IITA 1978). TMS 30001 has been recommended for intercropping because it branches higher than most cassava cultivars. Clone 58308, which has been found to have high combining ability for resistance to CBB and CMD, good yield, and low HCN, is a good parent to use in breeding new varieties.

These improved clones have outyielded local Nigerian varieties by a factor of 2–18 under epiphytotic conditions, especially with CBB. When intercropped with maize, they yielded three times that of the local (Hahn et al. 1979). They have also outyielded, by up to 16 times, local varieties in several African countries including Sierra Leone, Tanzania (Zanzibar), Zaire, Seychelles, as well as India.

The population-breeding program being carried out at IITA has therefore proved itself. It is now possible to maintain, in vitro, all germplasm material of more than 2000 accessions as well as newly bred varieties, instead of the laborious live maintenance method by regular field planting. Improved material in tissue culture of eight clones has been sent to more than 20 different countries and is available to those who ask for it and satisfy simple, phytosanitary conditions.

Although no selections have been made for improved keeping qualities in cassava, cultivar differences exist in the thickness of the peel and, particularly, in the adherence of the outer skin to the inner skin (Doku 1980). These characteristics, in addition to the various inner and outer skin textures and colours, could be indicative of cultivar differences in resistance to wounding, and, hence, to primary and secondary infections during storage. Booth (1975) has noted cultivar differences in the time to the onset of deterioration and in the rate at which deterioration advances.

Booth's (1975) clamp-and-box storage techniques prolong storage life of roots by up to 8 weeks. The indications, therefore, are that varieties with desirable root–skin characters could be stored according to Booth's clamp-and-box techniques far beyond 8 weeks.

YAMS

The major physiological factors limiting yield of yams have been found to be the mutual shading of leaves and the low capacity of the tubers to attract assimilates during early growth. Highly positive correlations have been found between D and tuber yield (Chapman 1965 for D. alata; Enyi 1972a, 1973 for D. esculenta and D. rotundata). Because of the excessive shading, D in
yam is low and a major source of yield limitation, particularly in *D. alata* and *D. rotundata*. As regards partitioning of assimilates and sink strength, recent work by Okoli (1980) on *D. rotundata* and *D. alata* indicates that high HI per se does not necessarily produce high harvestable tuber yields. Therefore, in breeding programs, high HI should be considered together with high dry-matter yields, large photosynthetic area, and high photosynthetic efficiency.

The progress in effecting hybridization and seed setting has been slow and has curtailed exploitation, on a large scale, of genetic differences in physiological yield determinants. Although methods of promoting flowering and of controlling sex expression are yet to be worked out, recent work reported by Akoroda et al. (1980) and Wilson (1982) indicates that it is possible, by methods of artificial pollination, to raise large numbers of seedlings. This means that, for all cultivars except the nonflowering types, superior characters can be selected and recombined and their genetic bases can be worked out, as Hahn (1977) reported in his preliminary work on source–sink relationships in the sweet potato. Breeding for physiological characters that improve yields in yams should, therefore, not be far off.

As is the case with cassava, the most important factors limiting yam production are diseases and pests. Nematodes — *Scutellonema*, *Meloidogyne*, and, to a lesser extent, *Pratylenchus* — cause serious damage both in the field and during storage. Foliar diseases including yam virus and leaf spots such as *Cercospora* and *Colletotrichum* reduce yields in some areas, and the yam tuber beetle *Heterolygus meles* causes conspicuous damage. Storage losses caused by nematodes, fungal and bacterial rots are high and are further increased by rodent attack, insect damage — scale insects and mealybugs — and respiration and sprouting (Wilson 1982).

Another limitation to productivity is the high production costs — largely a reflection of labour requirements at planting and harvesting; staking; and the large amount of planting material required.

Researchers, therefore, need to breed or select yams that, in addition to having high tuber yields and good culinary qualities, have resistance to pests and diseases and store well. Other focuses should be characters that will eliminate staking; reduce the amount of planting material; and facilitate mechanical harvesting — i.e., several small tubers that are shallow setting, oval, round, and uniform with a tough (thick) periderm. (A thick periderm would also reduce postharvest losses.)

There are not many *Dioscorea* species or cultivars with these desirable characteristics, and plans in Ghana are to start mutation breeding in collaboration with the International Atomic Energy Agency, Vienna, with the principal aim of obtaining self-supporting, early maturing mutants. Knowledge of flowering, seed set, pollination, and hybridization techniques is already available and is being expanded. Therefore, incorporating desirable characters from the mutants in breeding populations should not be difficult.

In the meantime, the genetic diversity exhibited in seedling populations as a result of artificial hybridization is being exploited by several countries, and, to date, IITA has tested more than 60,000 genotypes, mainly of *D. rotundata* seedlings, in several locations representing different cultural and ecological conditions. Selections are being made under both staked and unstaked conditions for yield, earliness, pest and disease resistance, tuber conformation, quality, and storability. Considerable genetic variation has been reported for all these characters (Sadik and Okereke 1975).

Hahn and Hozyo (1980) believe that it should be possible to obtain varieties with fresh tuber yields of 10–20 t/ha attainable in 6–11 months and that 40 t/ha can be obtained during similar periods with good cultivars (female *D. rotundata* plants, for example) and management.

Of all the *Dioscorea* species, *D. dumetorum* can be stored in the ground the longest without adverse effects but hardens within 3–4 days after harvest. Farmers, therefore, leave the tubers in the soil and harvest a few at a time. There are cultivar differences in the hardening character, and a Cameroon local cultivar, Muyuka, can be harvested and kept for up to 2 months without hardening. Since Muyuka does not yield so well as other cultivars, a hybridization program is envisaged to combine the good storage qualities of Muyuka with a high-yielding cultivar Jakiri. Both cultivars flower and fruit readily, and the program is expected to yield good results (S.N. Lyonga, personal communication).

A rare species, *D. liebrechtisiana*, that is indigenous to Cameroon has also been found to store well in the ground. This long-season yam continues to grow during the dry season but may be harvested after 11 months. The periderm of the tuber is very thick and corky, which protects the tuber almost indefinitely from rotting. Yields are average, and consumer acceptability is good.
It should be possible through interspecific hybridization to incorporate the excellent qualities of this species into the more popular *D. rotundata—D. cayenensis*. *Dioscorea liebrechtsiana* has not been observed to flower, and methods of flower induction must be found before a breeding program can get under way (S.N. Lyonga, personal communication).

As nematode attack in the field predisposes tubers to storage rots, tubers of *D. rotundata* seedlings are routinely screened at IITA, Ibadan, for resistance to nematodes. Since 1979, more than 5000 seedlings from six resistant breeding lines have been screened. Four IITA accessions have been found to be reasonably resistant. They are TDr 779, TDr 820, TDr 817, and a Nigerian local cultivar Nwapoko, which yields between 25 and 30 t/ha.

Water yams (*D. alata*) have a reputation for storing very poorly. However, a few cultivars — generally round with firm pale-purple flesh (very much like some cultivars of cocoyam) — have remained intact in storage for more than 6 months, free from pests and diseases and without sprouting.

With the available knowledge of artificial polination, hybridization, seed germination, care of seedlings, etc., the stage is set for the incorporation of all these excellent storage characteristics into existing cultivars.

**SWEET POTATOES**

In an attempt to overcome one physiological constraint to high yields of sweet potatoes, researchers at IITA screened more than 10,000 sweet-potato genotypes (Sadik 1973) for low CO₂-compensation concentration as an index of photosynthetic efficiency (PE). However, plants selected as having high PE did not produce significantly higher biomass than did genotypes with lower PEs. Later, PE was observed to be less important than assimilate distribution as a limiting factor to high yields. Genetic studies on crosses involving clones with high and low PEs revealed that PE was controlled largely by non-additive genes as well as other factors inversely related to it (Hahn 1977).

The major constraints to sweet-potato production in Africa are weevils and viruses. Work at IITA, in particular, has concentrated on these two constraints. Yield reduction from viruses has been estimated to be 78–80% in Nigeria (IITA 1975) and 57% in Uganda (Mukiibi 1977). Weevils damage both tubers and leaves in the field and also reduce quality, storability, and market value.

The IITA improvement program, which was initiated in the early 1970s with the evaluation of more than 10,000 seedlings, has accomplished much. Seeds from improved populations have been sent to many African countries, and currently material in tissue culture is being widely distributed. More than a dozen resistant clones, which yield 13–30 t/ha and are acceptable to consumers, have been bred. Of the four most virus-resistant clones developed, three are among those selected for weevil resistance (Terry 1979).

At IITA, weevil resistance has been found to involve delay in larval development on roots. Also, resistant roots have been observed to be relatively high in dry matter and low in protein and sugar. Biological analyses are in progress to ascertain the substances responsible and, hence, the mechanisms involved in resistance (Doku 1980).

In Cameroon, there is a weevil-resistant cultivar with a pinkish skin and gray–white flesh that produces a lot of mucilage. The role of mucilage in weevil resistance is, therefore, being investigated (Doku 1980).

When the factors responsible for resistance are found, breeding for weevil resistance should be possible by selecting and crossing the appropriate genotypes from seedling or clonal populations. Therefore, the possibility to increase yields beyond 30 t/ha is good. Research to find solutions to the sterility—compatibility phenomenon within the species must be intensified to widen the scope of hybridization and, hence, the genetic base of available varieties.

**COCOYAM**

The relationships between physiological determinants and yield in both *Xanthosoma* and *Colocasia* have been studied by Moursi (1954); Purewal and Dargan (1957); Enyi (1967a,b, 1968, 1977a,c); Ching (1970); Ezumah and Plucknett (1977); Abit and Alferez (1980); Sivan (1980); and Wilson (1980, 1981b). Almost all of this work was done in Asia. In both species, leaf area, LAI, and D were found to be closely related to yield, and strong positive correlations were reported between corm or cormel yields and leaf area.

To exploit the full potential of both species, Wilson (1981b) urges the selection of plants with large canopies that develop rapidly and last a long time. Also important is leaf angle (or leaf orientation) that varies from 47° to the vertical to almost horizontal (70–80°), as well as petiole length and angle. Petioles of some cultivars are
very large and may constitute an unnecessary sink in competition with corms and leaves that are the important economic products. Ability to control weeds and erosion has also been found to be an important physiological attribute.

Recent developments in techniques of inducing flowering with gibberellic control (Alamu and McDavid 1978a, b) have now opened the way for geneticists to study important yield-related characters in *Xanthosoma* and *Colocasia* and for breeders to combine the useful characters to produce elite varieties. Several improvement programs based on hybridization and selection are already under way.

Field and storage rots are the major constraints to cocoyam production. Several organisms appear to be associated with rot, and yield losses have been estimated to be between 40% and 90% (Arene and Okpala 1981; Muduewesi et al. 1981; Okeke 1981).

Recent research in Nigeria and Cameroon has revealed potential sources of resistance among *Xanthosoma* hybrid seedlings from crosses between local and Caribbean accessions. This indicates that resistance may be present within the gene pool in both countries. Efforts should be made to select for the most suitable accessions to form the basis of a comprehensive breeding program for disease resistance.

Current production of any crop is the culmination of several processes that start with planting and end with the consumer. The processes include germination (sprouting in the case of asexual propagules); crop establishment; competition with weeds; interception and utilization of solar energy — hence, photosynthesis and biomass production; partitioning of biological yield into economic yield; tolerance or resistance to field and storage pests and diseases; resistance to damage and deterioration during harvesting, transportation, storage, retailing, etc.

These desirable attributes should remain fairly stable in elite varieties for many years under the various environmental conditions in which the crops are grown. The degree of excellence at every step in the process determines yield. Productivity, therefore, involves more than economic yield per se, or its immediate precursors (biological yield and harvest index). It is a complex interaction grounded in ontogeny. Knowledge of each attribute that affects yield is necessary to push current production levels nearer to the potential. Considerable work has been done through selections for yield per se, followed by selections for resistance to field pests and diseases. The efforts have resulted in phenomenal increases in the yields of cultivars. However, work on physiological characters related to yield should be intensified and serious attention paid to the improvement of postharvest characteristics, without which most of the improvements in yield will be eroded before reaching the consumer.

The extent to which activities in crop improvement, agronomy, crop protection, farming-systems research, etc. have succeeded in tapping potential could be summarized according to:

- Exploration for and maintenance of genetic diversity within the species and related wild species whose useful genes can be incorporated into the cultivated species;
- Knowledge of the strategy of economic-yield attainment and the development of suitable agronomic practices to overcome production bottlenecks;
- Research capability to develop productive and adapted varieties through improved breeding and selection techniques;
- Maintenance and distribution of improved varieties together with a package of appropriate production techniques; and
- Overall performance of improved varieties

In the various growing areas vis-à-vis the numerous production constraints — i.e., pests and diseases, drought, etc.

The results of efforts so far range from poor to excellent, with cassava clearly the leader, followed closely by sweet potatoes, and cocoyams being the poorest. However, for all these crops, solid foundations are being laid under the leadership of IITA, the quality of whose work is gradually being appreciated and adopted by all countries. My forecast is that, by the end of the 1980s, we will get close to the production potentials estimated for these crops.