TROPICAL YAMS AND THEIR POTENTIAL

Part 4. *Dioscorea rotundata* and *Dioscorea cayenensis*

Agriculture Handbook No. 502

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
in cooperation with
Agency for International Development

PREFACE

The feeding of future generations requires a knowledge of the individual crop plants of the world and their potentials. Crops can be recommended for use in particular regions only on the basis of potential yield, the costs of production, the food and feed value of the crop, and the way the crop can be processsed or otherwise used. For most of the major food crops of the world, a body of information is already available. However, tropical roots and tubers, which are widely used as staple foods, have been largely neglected. Only in recent years has an awareness been growing of the potential of these crops to supply large amounts of food in relatively small amounts of space.

Yams are the second most important tropical root, or tuber, crop. The annual production, perhaps 25 million tons, places them second in importance to cassava. But yams are better food than cassava, and while they are usually thought to be more difficult to grow, under some conditions yams outproduce cassava. Yams fill an important role in the diet of many areas of the Tropics—a role that can increase in importance. That role and its potential are not, however, well understood.

The yam is not a single species. Perhaps 60 species have edible tubers; of these about 10 species can be considered crop plants. The literature concerning these species is widespread but fragmentary. This is the fourth of several Agriculture Handbooks in which the major species of yams are individually treated in order to bring the investigator as well as the agriculturalist up to date with respect to the status of these important plants. This is part of a research effort cosponsored by the Agricultural Research Service of the U.S. Department of Agriculture and the Agency for International Development to introduce, evaluate, and distribute better yam varieties.

Also in "Tropical Yams and Their Potential" series—
- Part 1. *Dioscorea esculenta.* USDA Agriculture Handbook No. 457.
- Part 2. *Dioscorea bulbifera.* USDA Agriculture Handbook No. 466.
- Part 3. *Dioscorea alata.* USDA Agriculture Handbook No. 495.

CONTENTS

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TROPICAL YAMS AND THEIR POTENTIAL

Part 4. *Dioscorea rotundata* and *Dioscorea cayenensis*

By FRANKLIN W. MARTIN and SIDKI SADIK[1]

INTRODUCTION

Although other yam species have been introduced in Africa, in West Africa the word "yam" is almost synonymous with *Dioscorea rotundata* (L.) Poir., the African white yam. There, this species is associated with millennia of cultivation and probably with the origins of agriculture itself. It is an old staple food, but a crop that has suffered from the encroachment of rice, cassava, and cocoyams. Nevertheless, it remains the starchy food of choice and certainly the prestige food to be served to guests. *Dioscorea alata* L. might be more widespread and might outyield *D. rotundata,* but *D. rotundata* is usually enthusiastically preferred.

Although *D. cayenensis* Lam. is a sister species of *D. rotundata,* they can be easily distinguished. The two species have apparently hybridized frequently, and intermediate forms impede exact classification. Therefore, this second most important African species is also considered here. The evidence for one versus two species will be considered, but the reader should be aware that the problem has not been resolved to everyone's satisfaction. The names themselves are often used interchangeably.

With the decline in the use of yams throughout the Tropics, including West Africa, it is particularly appropriate to consider the virtues and weaknesses of these two species, to see what their potential is.

Domestication

In the forests of West Africa, in particular from the Ivory Coast to Cameroon, *D. rotundata* and *D. cayenensis* were domesticated. The exact process of domestication is not recorded, but it

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is agreed that the highly developed tribal civilizations of West Africa arose in connection with yam cultivation. Alexander and Coursey (*1*)[2] have collected the sparse information about yam domestication and have drawn a fairly detailed picture of what might have happened during the course of domestication.

The succulent tubers of yams were probably encountered many times by primitive food-gathering peoples roaming the forests of Africa. (Indeed, wild yams are still sought.) Among the many kinds of yams, they were able to distinguish the poisonous species, which they detoxified by soaking the macerated tuber in water. In spite of the risk associated with them, they have continued to be prized even in modern times, although the convenience of the nonpoisonous forms has probably led to their more frequent use.

Domestication might have occurred at the homesite. Tubers carried there and saved for later consumption might have sprouted and developed new plants, or the woodier head pieces that are often discarded might have sprouted. The idea for planting yams could have come from the observation that plants near the home are more convenient to use.

On the other hand, Coursey and Coursey (*10*) have suggested that the beginnings of yam cultivation might be found in religious sanctions against the out-of-season use of the tuber. Such sanctions effectively prevented the premature use and destruction of plants before propagation could be achieved. Further steps in protecting yams were then considered. It is probable that the cultivation of the yam, which requires a minimum of 6 months, was associated with the establishment of villages. These, in turn, made stable agriculture possible.

D. rotundata appears to be a fairly ennobled species. Although sexual fertility has declined, it has not been lost completely, as in the case of *D. alata*. Wild forms are not definitely known, but many cultivars look like the wild *D. praehensilis* Benth. and other related species. It is highly probable that during domestication of *D. rotundata* a sporadic exchange occurred between the cultivated and wild forms. Through occasional hybridization with wild forms, the cultivated types were enriched and their evolution was encouraged. On the other hand, *D. cayenensis* is definitely a more primitive species. Wild forms can be found as far west as Sierra Leone and are used as food without cultivation.

The development of improved strains may have been an unconscious process. Generations of planting from the better cultivars followed by frequent outcrossing is probably the most efficient technique for long-term plant breeding. But the historical

[2] Italic numbers in parentheses refer to items in "Literature Cited," p. 35.

processes involved have been forgotten. What one finds now in West Africa is a widespread appreciation of yam cultivars for their particular characteristics and a recognition of value even in minute differences.

Coursey and Coursey (*10*) have described the new-yam festivals common throughout the Yam Belt. The elaborate beliefs and practices appear to have one essential purpose, the inhibition of eating of yams before they are mature. It was, and still is, wise to permit tubers to grow to near their maximum size before using them. The usefulness of the ceremonies in the growth of a relatively high-level culture is quite understandable. It is probable that the ennoblement of the species has been intricately involved with the religious forms regulating and protecting the species.

Distribution

The Yam Belt, where the majority of African yams are found, extends from the Ivory Coast to Cameroon, a distance of about 3,200 kilometers (fig. 1). Yams are usually not found near the seacoast, but their production begins within a few to about 160 kilometers from the coast and continues for one to several hundred kilometers inland. This is an upland region, often of rolling hills, where rainfall is regular enough through one or more periods to permit the plants to mature.

Little is known of the prehistorical distribution of yams outside the Yam Belt. The impression frequently given is that African yams do not grow outside this belt. However, while not as likely to be a staple food, yams are cultivated at least as far north as Senegal, in quantity in Sierra Leone, and to a sufficiently great extent in the Congo. The West African yams occur in limited

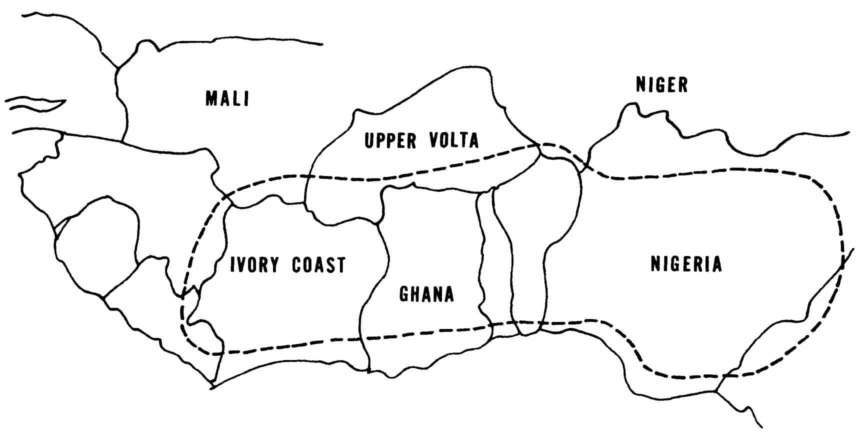

FIGURE 1.—The Yam Belt of Africa, showing principal regions where *D. rotundata* and *D. cayenensis* are located.

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areas in Tanzania and possibly other regions of East Africa where climatic conditions are suitable.

Outside Africa, the West African yams are very sporadically distributed, and their occurrence in particular regions appears to be due to historical accident. In the Caribbean, for example, the pattern of cultivation is not rational; whereas very good cultivars of *D. rotundata* are important in Jamaica, Puerto Rico, and the French West Indies, they are virtually unknown on other islands. The African yams are seldom seen in Southeast Asia or on the islands of the Pacific except in New Caledonia, where they were introduced by the French. In several areas of Brazil they have also become important.

Wide distribution of the West African yams appears desirable. Because of their adaptability to areas somewhat drier than those where *D. alata* is grown and because of the earliness of most cultivars, the African species, especially *D. rotundata,* should be able to fill a special niche where other species of yams are less successful.

BOTANY

Classification

Both *D. rotundata* and *D. cayenensis* belong to the section Enantiophyllum, the most important section of the genus. The section is known only in the Old World. Tubers of this section are usually vertical, and the leaves are simple. In addition to the two species under consideration here, the section includes the Asian species *D. alata* and *D. opposita* Thunb., and the important African species *D. abyssinica* Hockst., *D. colocasiifolia* Pax, *D. lecardi* de Wild., *D. liebrechtsiana, D. mangenotiana* Miège, *D. praehensilis* Benth., and several others, some of which are used for food under special circumstances. Both the Asian species, about 50, and the African have been described by Burkill (*4, 5*).

In common with other yams, the species mentioned above belong to the family Dioscoreaceae, of which *Dioscorea* is the principal genus. The family is usually classified among the monocotyledons, although some evidence of a second cotyledon has been found (*16*). The family is characterized by rhizomes, usually reduced to a nodeless structure, the tuber. Male and female flowers, usually on separate plants, are small and often inconspicuous. The floral pattern is based on sets of three.

To some, *D. rotundata* and *D. cayenensis* are the same species, whereas to others the former is a botanical variety of the latter. The taxonomic controversy is far from resolution. Characteristics generally attributed to the more clear-cut forms of the two species are given in table 1. Ayensu has found subtle anatomical differences that indicate separate species (*3*). In spite of Ayensu's excellent distinction, many intermediate forms of the two species occur, and these add to the confusion. Such forms are probably hybrids or hybrid derivatives. However, the occurrence of hybridization has not been rigorously demonstrated.

The existence of wide variation among the varieties of *D. rotundata,* and to a lesser extent, of *D. cayenenesis,* and the occurrence of other species in the same section cause classification difficulties. Excellent keys in English have been developed by Miège (*21*), Waitt (*29*), and Lawton and Lawton (*16*). However, the first recognizes only one species, and the second and third, two species. Among the key characters common to both species are simple leaves, presence of spines, annual stems and tubers, and absence of aerial bulbils. The males, when in flower, can be identified from the flowers as well.

Morphology

D. rotundata and *D. cayenensis* are vigorous vines that climb by twining to the right (fig. 2). Their foliage may be entirely glabrous, and it may have a purplish waxy bloom. Spines are very common, especially on the lower and larger stems. The stems may be somewhat striated vertically, and the diameter varies among varieties. The length of the vine varies, but heights of 10 meters are easily accomplished.

The leaves are extremely varied (fig. 3). Their length varies from 4 to 20 centimeters. Shapes are ovate, cordate, or almost orbicular. The form of the leaf is also influenced by the degree of folding, reflexing, cupping, undulation of the margins, and the position on the plant. In addition, leaves vary in number of veins, in presence and size of lobes, in the size of the sinus between lobes, in rugosity, and in intensity of color. These traits, or combinations of traits, are useful in identifying varieties.

Leaf veins and stems contain variable amounts of anthocyanin, but in contrast to *D. alata,* the two African species are

TABLE 1.—*Most common differences between* D. rotundata *and* D. cayenensis

Trait	*D. rotundata*	*D. cayenensis*
Growing season	7 to 8 months	10 to 12 months.
Climatic preference	Intermediate rainfall	High rainfall.
Leaf shape	Narrowly ovate	Broadly ovate.
Number of harvests	2	1.
Possible time of harvest	Limited, late summer to winter.	Almost year round.
Tuber color	White	Yellow.

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FIGURE 2.—The foliage of *D. rotundata.*

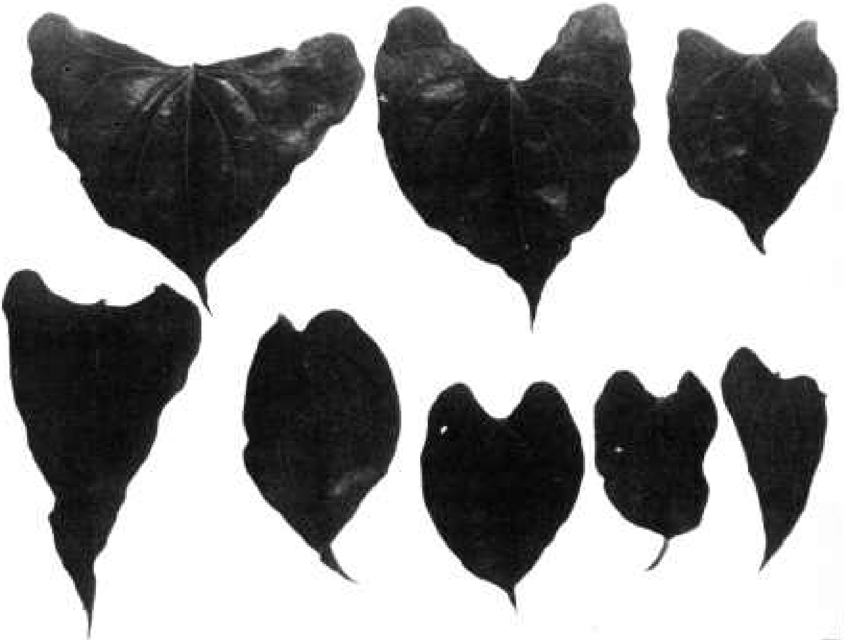

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FIGURE 3.—Variations in leaf shapes of *D. rotundata* and *D. cayenensis.*

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FIGURE 4.—Petiole and nodal structure of *D. rotundata.*

never brightly colored by anthocyanin. Anthocyanin coloration is a varietal trait. The petioles are usually enlarged at the two extremes (fig. 4) and may be striated.

The flowers of *D. rotundata* and *D. cayenensis* are usually produced early during the vegetative cycle. In Ibadan, Nigeria, most *D. rotundata* and *D. cayenensis* cultivars usually start flowering in June. The percentage of flowering plants in a yam field is low, and among plants that flower, there is a preponderance of male over female plants. *D. cayenensis* usually produces male flowers and seldom female flowers. *D. rotundata* usually produces male and female flowers on separate plants. Sadik and Okereke (*27*) reported plants that produce either male, female, or complete flowers on the same plant.

The male flowers of *D. rotundata* are 1 to 3 millimeters in diameter, sessile, and borne on spikes subtended by small bracts. The perianth is slightly connate at the base and consists of three light-green sepals and a corolla of three light-yellow petals. The androecium consists of two whorls of three stamens each. Anthers are basifixed on short, slightly connate filaments and are composed of two thecae dehiscing in extrorse and introrse fashion. The highly vacuolated pollen grains are small and sticky, which makes pollination by wind impossible.

Female flowers are seen infrequently in *D. rotundata* and even less seldom in *D. cayenensis,* a consequence of the complex determining mechanism that results in more males than females. Female flowers occur on axillary spikes and are about 0.5 centimeter long. The perianth consists of two whorls of three sepals and three petals, which are lobed over the ovary. The pistil is single, with a trifurcated stigma. Two to three staminodes are sometimes present and are located peripherally to the style. The ovary is inferior and trilocular, with each locule containing two ovules. Upon maturation, the perianth dries out while the ovary continues its development into a capsule, which opens vertically and releases up to six seeds with thin leathery wings that help in seed dispersal.

The tubers of both species are much less variable than those of *D. alata.* They are most commonly cylindrical and seldom branched (fig. 5). On encountering an obstacle a tuber may develop a foot, lumps, or appendages. The tuber skin, being thick and corrugated, provides good protection in storage. The size of the tuber varies from less than 200 grams in wild types to about 25 kilograms in cultivated varieties.

The flesh of the *D. rotundata* tuber is white and because of the presence of vascular bundles around which starch deposits are

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FIGURE 5.—A collection of *D. rotundata* tubers in Ghana.

formed, appears curdlike. The flesh of *D. cayenensis* is usually yellow and smoother than the flesh of *D. rotundata.*

Aerial tubers are seldom produced but may be stimulated by accidental or intentional girdling of the stem.

Cytology

Chromosome numbers of *Dioscorea* are based on multiples of 9 and 10, the latter being the most common (*16*). Miège has postulated a third basic number of 12 (*20*). Odd numbers of chromosomes deviating from these multiples have been reported and indeed could partly account for the sterility of some species, but such numbers are hard to verify. The chromosomes of *Dioscorea* are particularly small, and determination methods, very tedious.

Chromosomes of the African species have been counted by Miège (*20*). Races of *D. rotundata* and *D. cayenensis* have either 36 or 54 chromosomes. These numbers correspond to tetraploid and hexaploid numbers, respectively. In the Ivory Coast the 36-chromosome races are found in the north and the 54-chromosome types in the south. In the 36-chromosome races, meiosis is normal, which suggests that the species is a very old tetraploid. Occasional reproductive failures and sterilities in open pollinations and controlled crosses could be associated with hexaploid numbers.

The study of chromosome numbers has not been sufficiently extensive to well characterize the two species. Wider study could shed light on their origins and their relationships. However, this field of study has been neglected in recent years.

The production of seed by female plants is not common but is enhanced by planting several varieties together. Seedlings have been grown by a number of different investigators in what might be described as preliminary breeding attempts. The seedlings are quite tender and may require 2 years to produce a suitably large tuber. Breaking of the normal dormancy period, which inhibits germination during the dry season, may make possible a 1-year seed-to-seed cycle.

Efforts to breed *D. rotundata* have been begun by Sadik and Okereke (*27, 28*) at the International Institute of Tropical Agriculture in Ibadan, Nigeria. Three generations of plants, about 40,000, have been raised from seeds produced by natural crossing. These plants flower readily and cross with ease; moreover, they exhibit a wide spectrum of genetic diversity in respect to disease resistance, degree of flowering and fruiting, and many morphological features. The use of seeds has increased the percentage of flowering offspring twofold over plants grown from tuber cuttings, and the percentage of female plants and the number of flowers and fruits per plant have also increased. Of interest is

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the production of monoecious plants, which could provide self-pollination capabilities for breeding. In addition, a number of plants have been dwarf or semidwarf, ranging in height from 30 to 70 centimeters. These could be important in that such plants do not require staking.

Characteristics of importance in breeding include tuber shape and size, disease resistance, and eating and pounding quality.

CULTIVARS

No collection was ever assembled that was sufficiently extensive to make possible an estimate of the number of cultivars of *D. rotundata* in existence. Unlike the examples of *D. alata* and *D. esculenta,* the sexual fertility of *D. rotundata* and *D. cayenensis* suggests that new seedlings are constantly arising. Although cultural practices are such that one might not expect the establishment and selection of new seedlings, the variation in cultivars throughout West Africa suggests that this indeed has occurred. Normally only a few cultivars are favored in a particular environment, although many more are recognized. Each cultivar occupies a particular niche according to its special characteristics that make it in demand. The intense localization of cultivars, so characteristic of West Africa, adds confusion to the picture. It is the authors' opinion that the number of varieties throughout West Africa is between 500 and 2,500.

The characteristics already mentioned distinguishing the two species are also varietal distinguishing characteristics. A complete list of characteristics observed in studying over 200 accessions of the two species is given in table 2.

The particular characteristics that are of value in a select cultivar include yield at first harvest, a complex of components. While dependent on many factors, good yielding ability is generally easily recognized by the farmer, and certain cultivars are maintained for their yield, even though other characteristics may be suboptimal. After yield, probably the most important characteristic is the suitability of the tuber for fufu, the pounded yam product so important to West Africans. In a particular region the suitability of local cultivars for this use is well known.

Often not recognized is the different susceptibility of varieties to virus diseases. Viruses, when present, drastically reduce production, especially when transmitted through the seed tuber to a new generation of plants. It is highly likely, however, that either consciously or unconsciously the more diseased tubers are eliminated during the normal course of culture in two-harvest systems. (See "Harvest and Yield.") When two harvests are made, the regrowth of the tuber is severely limited in the case of badly

(Continued on page 15.)

TABLE 2.—Dioscorea rotundata *and* D. cayenensis *characteristics and rating system*

Number	Characteristic observed	Rating system	Scale and extremes
1	Number of stems per plant	Counted	1 to many.
2	Branching tendency of lower stem.	Absence or presence of branches, 0.5 meter.	1=no, 2=yes.
3	Anthocyanin content of stem	Estimated visually	0=none, 5=maximum.
4	Amount of wax on lower stem.	do	Do.
5	Quantity of thorns on stems	do	1=minimum, 5=maximum.
6	Presence of striations on stems.	do	1=minimum, 5=some.
7	Anthocyanin content of petiole.	do	1=minimum, 3=maximum.
8	Presence of striations on petiole.	do	0=none, 3=maximum.
9	Length of petiole compared to leaf blade.	Checked by hand	1=less than ½ blade length, 2=longer.
10	The extent to which the petiole ears encircle the stem.	Estimated visually	1=little, 3=much.
11	Type of leaf	Judged by a somewhat linear scale.	1=deltoid, 2=shield, 3=intermediate, 4=ovate, short, 5=ovate, 6=ovate, long.
12	Intensity of virus symptoms of young foliage.	Estimated visually	0=none, 5=maximum.
13	Anthocyanin content of leaf	do	Do.
14	Amount of wax on leaf	do	Do.
15	Green color intensity of leaf	do	1=very light green, 5=very dark green.
16	Yellow shading of foliage	do	0=none, 5=maximum.
17	Shape of leaf	Judged only with respect to length and width.	1=ovate, 5=deltoid.
18	Bluntness of lobes of leaf	Estimated visually	1=very pointed, 5=very blunt.
19	Development of an apical tail.	do	1=minimum, 5=maximum.
20	Smoothness of leaf surface	do	1=very rugose, 5=very smooth.
21	Leatheriness of leaf	Estimated by feel	1=not leathery, 5=very leathery.

TABLE 2.—Dioscorea rotundata *and* D. cayenensis *characteristics and rating system*—Continued

Number	Characteristic observed	Rating system	Scale and extremes
22	Upward folding of leaf lobes to form a cup.	Estimated visually	1=minimum, 5=maximum.
23	Upward folding of leaf along main vein.	do	Do.
24	Downward arching of leaf along main vein.	do	Do.
25	Undulation of leaf margins	do	Do.
26	Internode length of stem	A large lower internode, measured.	Centimeters.
27	Leaf blade length	The length of a large lower leaf blade, measured.	Do.
28	Leaf blade width	The width of the same leaf, measured.	Do.
29	Lobe length	The length of the lobes from petiole junction to tip, measured.	Do.
30	Petiole length	The length of the petiole, measured.	Do.
31	Internode length divided by blade length.	Calculated	Ratio near 1.
32	Blade width divided by blade length.	do	Do.
33	Lobe length divided by blade length.	do	Do.
34	Petiole length divided by blade length.	do	Do.
35	Field vigor of entire plant	Estimated visually	1=weak, 5=vigorous.
36	Intensity of virus symptoms	do	0=no symptoms, 5=maximum.
37	Density of foliage	do	1=low density, open, 3=high density.
38	Reclassification of leaf type	Classified by a nonlinear system.	1=deltoid, 2=shield, 3=almost circular like *D. cayenensis*, 4=intermediate to the two species, 5=small ovate typical of *D. rotundata*, 6=typical ovate,

TABLE 2.—Dioscorea rotundata *and* D. cayenensis *characteristics and rating system*—Continued

Number	Characteristic observed	Rating system	Scale and extremes
38	Reclassification of leaf type—Continued.	Classified by a non-linear system.	7=large but ovate, 8=long, typical ovate.
39	Estimated potential as a cultivated variety.	Estimated visually from vigor and virus symptomology.	1=poor potential, 5=high potential.
40	Number of tubers per plant	Estimated as tendency towards multiple tubers.	1=tubers always solitary, 5= tubers always multiple.
41	Form of tuber	Estimated visually	1=spherical, 5=long and narrow.
42	Tendency of tuber to branch	do	0=no branching, 5=highly branched.
43	Place where tuber branches	Observed	1=uppermost part of tuber, 5=lowermost part of tuber.
44	Uniformity of tuber shape	Estimated visually when several are compared.	1=not uniform, 3=very uniform.
45	Length of tuber	1 normal tuber, measured.	Centimeters.
46	Diameter of tuber	do	Do.
47	Ratio of tuber diameter to tuber length.	Calculated	A ratio usually less than 1.
48	Rugosity of the tuber surface.	Estimated visually	1=smooth, 3=rugose.
49	Hardness of the cortex of the tuber.	Estimated by peeling with fungus nail.	1=soft, 3=hard.
50	Roots on the surface of the tuber.	Estimated visually	0=none, 3= many.
51	Average damage done to tuber surface by insects.	do	0=none, 3= extensive.
52	Intensity of yellow color of cortex.	do	0=no yellow color, 3= maximum.
53	Yellow color of flesh of upper part of tuber.	do	Do.
54	Yellow color of flesh of lower part of tuber.	do	Do.
55	Gradient of color difference from top to bottom.	do	0=color uniform, 3=strong color gradient.

TABLE 2.—Dioscorea rotundata *and* D. cayenensis *characteristics and rating system*—Continued

Number	Characteristic observed	Rating system	Scale and extremes
56	Uniformity of cross section of tuber.	.... do	1 = not very uniform, 3 = highly uniform from cortex to center.
57	Tendency of flesh to discolor from oxidation.	Estimated visually 5 minutes after cutting.	0 = no tendency, 3 = maximum tendency.
58	Amount of gums released by cut tuber.	Estimated visually ..	1 = minimum, 3 = maximum.
59	Grainy appearance of cortex .	.... do	0 = smooth, 3 = very grainy.
60	Thickness of cortex	.... do	1 = thin, 3 = thick.
61	Ability of cut tuber to sting human flesh.	Estimated from feeling when tuber rubbed on arm.	0 = no ability, 3 = maximum.
62	Peeling ease in the kitchen ..	Estimated by peeling tubers.	1 = difficult, 3 = easy.
63	Cooking time to softness	Measured	Minutes.
64	Discoloration of cooking water.	Estimated visually ..	1 = minimum, 3 = maximum.
65	Favorable cooked appearance .	Judged	1 = appears poor, 3 = appears good.
66	Amount of color in cooked tuber.	Estimated visually ..	0 = white, not colored, 5 = highly colored.
67	Attractiveness of the cooked tuber with respect to color alone.	.... do	1 = not attractive, 3 = very attractive.
68	Erosion of tuber piece in cooking.	.... do	0 = no erosion, 3 = much erosion.
69	Texture of cooked tuber as experienced in the mouth.	Judged by chewing ..	1 = smooth, 3 = grainy.
70	Stickiness of cooked tuber piece.	Estimated by feeling.	1 = not sticky, 3 = very sticky.
71	Flavor acceptance to investigators.	Judged on eating ...	1 = not acceptable, 3 = very acceptable.
72	Moisture in cooked tuber	Estimated on eating .	1 = dry, 3 = moist.
73	Bitterness of taste	Estimated on eating .	0 = not bitter, 3 = very bitter.
74	Overall value as cooked tuber .	Judged on the basis of all relevant factors.	1 = unacceptable, 3 = superior.
75	Sweetness of cooked tuber ...	Estimated on eating .	0 = not sweet, 3 = very sweet.

diseased plants, and the second, or seed, tuber is not produced or is too small to use. The vigor of the disease-free materials probably assures their preferential selection.

Storability, closely related to dormancy duration, is also highly important in a select cultivar. Keeping quality during long storage is desirable, but germination should occur readily after planting. Storability is highly related to resistance to insects and fungi and is a trait that is normally recognized by farmers.

It is very difficult to get a clear picture of superior cultivars in West Africa. In the sparse literature, nevertheless, certain cultivars are frequently mentioned. Since in most cases cultivars have not been tested in more than limited areas, it is very difficult to compare cultivars from different countries. Some better cultivars mentioned in the literature or known to the authors are listed in table 3.

From a collection of over 200 cultivars of *D. rotundata* and *D. cayenensis* at the Mayagüez Institute of Tropical Agriculture, 12 outstanding varieties were selected (table 4). Free seed pieces are available in January and February for shipment to tropical regions where they might be of use. An important characteristic of all these cultivars is that they resist virus. (See "Pest Control.") While not immune, they develop heavy vegetative cover and yield well. In spite of susceptibility to virus, roguing and seed-tuber selection can result in symptom-free plants.

CULTURE

Environmental Requirements

The African yams are found most often in forests, where they are adapted to climbing trees in search of sunlight. Cultivars

TABLE 3.—*Some of the better* Dioscorea rotundata *and* D. cayenensis *cultivars of the Tropics*

Source and cultivar	Number of harvests	Source and cultivar	Number of harvests
Brazil: 'Cará de Costa'	2	Jamaica: 'Negro'	2
Ghana: 'Puna'	2	Nigeria:	
Guadeloupe: 'Grosse Caille Corrosol'	2	'Aure'	1
Ivory Coast:		'Boki'	1
'Akandu'	1	'Guinea Blanco'	2
'Gnan'	1	'Igangan'	1
'Krenglé'	1	'Imowe'	2
'Lopka'	2	'Ounmodo'	2
'N'Detré'	2	'Olo'	1

TABLE 4.—*Superior cultivars of* D. rotundata *selected in Puerto Rico from a large collection*

Identification number[1]	Recent origin	Name
15085	Puerto Rico	'Guinea Blanco'.
15484	Ivory Coast	'Grosse Caille Corrosol'.
15493	Jamaica	'Negro'.
15656	Iwo, Nigeria	'Zaria'.
15660	do	'Etentu'.
15665	Kaiola, Nigeria	'Fele'.
15667	Iwo, Nigeria	'Boki'.
15668	Nigeria	Unknown.
15680	Umudike, Nigeria	'Awada'.
15711	Nigeria	Unknown.
15740	Dahomey	'Baniore Bagarou'.
15770	do	'Kourokouragourouko'.

[1] In the collection of the Mayagüez Institute of Tropical Agriculture.

are adjusted to climatic conditions reflecting their evolution in distinct ecological zones. *Dioscorea cayenensis* requires a fairly long rainy season, about 10 months each year. On the other hand, most *D. rotundata* cultivars can be grown with far less rainfall. Seven months of wet weather is often sufficient.

In most of West Africa the dry period corresponds to the latter months of the year, and both species produce and mature their tubers before the dry season begins. However, in *D. rotundata,* tuberization begins months earlier, as little as 4 months after planting. This capacity to tuberize at a very early stage may be an adaptation to very short rainy seasons. Different cultivars maturing at different times add some flexibility to the annual cycle of planting and harvest, but the annual growth cycle of a given cultivar is difficult to change.

When a collection of cultivars is grown in any one region, differences in growth patterns can be seen. In Puerto Rico the shortest time to complete a growth cycle has been 8 months, in the case of some cultivars of *D. rotundata.* When the normal growth cycle terminates, the foliage dies back, and only the tuber is left in the ground. This response, which is not well understood, occurs whether or not moisture is limiting. As a general rule, *D. cayenensis* cultivars mature very late—in Puerto Rico, about 11 months after planting.

Differences in time to maturity are related to differences in the length of the period of dormancy. Since the complete growth cycle always equals 12 months, early maturation is related to long storage life. Thus, storage life is short in *D. cayenensis* and

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FIGURE 6.—Yam mound in Nigeria.

longer but variable in *D. rotundata*. Since *D. rotundata* tuberizes early, a fairly large immature tuber may be present as much as 4 months before harvest. These immature tubers, if harvested before dieback of foliage, store longer than mature tubers but tend to sprout earlier in the year than mature tubers harvested later. It does not appear possible to change the annual cycle by planting such prematurely sprouted tubers.

Abundant and regular rainfall is desirable to produce maximum yields in the African yams. Most cultivars of *D. rotundata* can tolerate dry spells and can recuperate after a drought to produce almost normally. The foliage of both *D. rotundata* and *D. cayenensis* is much less succulent than that of *D. alata* and much less liable to wilt. Thus, although *D. alata* and *D. rotundata* are often grown together, the latter is more suitable when rainy seasons are short or unpredictable.

The early tuberization of *D. rotundata* makes feasible a type of double harvest not possible in the production of other species. After the tuber has formed, but 1 to 3 months before maturity, the tuber may be removed from the living plant without disturbing its growth excessively. The typical mound (fig. 6) in which African yams are planted facilitates this harvest. Since most of the roots arise from the upper, woodier portion of the tuber, the crown, it is possible to carefully dig around the tuber, cutting away the more or less rootless portion and leaving an intact system of roots. After the hole has been covered, the remnant of the tuber begins to produce a new tuber or tubers. Depending on cultivar, time of removal of the first tuber, and length of the remaining growing season, the newly produced tuber may be only large enough for use as seed or it may be as large or larger than the first tuber. The technique of two harvests is an excellent way to extend the length of the harvest season and indeed may be the chief advantage of *D. rotundata*.

The African yams are probably more tolerant of poor soils than are the Asian yams. The soils in Africa where they are produced are chiefly very acid lateritic clays. But among African crops they are one of the most exacting with respect to fertility. Therefore, they are usually planted on newly cleared land.

Land Preparation and Planting

Two techniques must be distinguished with respect to land preparation and planting, the African and the Caribbean. In Africa new land is used for yams whenever possible. The smaller trees and shrubs are cut and piled, and the larger trees are ringed. The brush is burned during the dry season. Mounds are then constructed with handtools. The size of the mounds and their form and spacing vary from region to region, but considerable uniformity is generally found in any one region. The mounds are usually the proper size for a single plant but may be large enough to accommodate a dozen or more.

Within the mound the seed tubers are planted with a small handtool. Custom dictates the depth of planting (5 to 15 centimeters) and the orientation of the tuber piece. In some places the pieces are not oriented, and in others it is thought necessary to locate the piece with stem end down. A mulch, sometimes of dried grass, is often placed over the mound. This has been found to reduce soil temperature and moisture loss and to lead to better sprouting.

In contrast to the method of planting yams in West Africa, mechanization of soil preparation has been accomplished in the Caribbean and other parts of the Tropics. The soil is turned deeply by moldboard plow. Large quantities (10 to 25 metric tons per hectare) of organic material are distributed over the soil and sometimes mixed with the soil by rototilling. A disk plow is then used to form the soil in ridges 1 to 1.5 meters apart and 0.3 to 0.5 meter high. The seed tubers are normally placed by hand and without orientation about 10 to 16 centimeters below the surface of the soil. This can be done with a planting machine.

In certain areas of Puerto Rico it is possible to plant yams without excessive soil preparation. When soil is deep and well

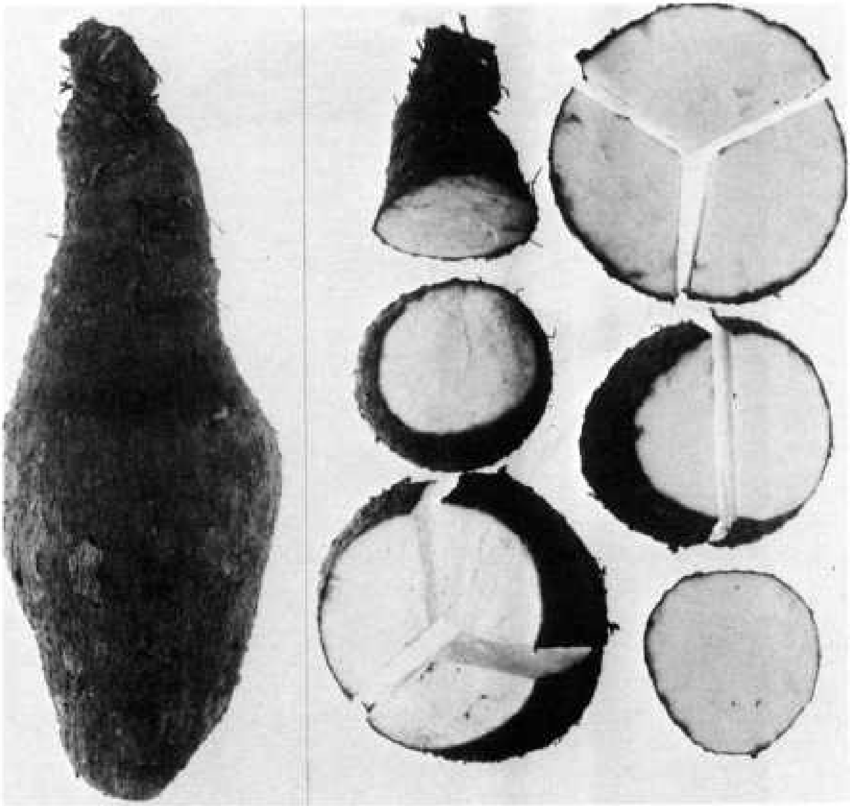

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FIGURE 7.—Kinds of planting pieces, from left to right, top to bottom: whole small tuber, head pieces, midpieces, tail pieces.

drained on slopes, the tuber pieces are planted without forking or plowing. Erosion is thus minimized, but weed control becomes critical. Weeds must not be allowed to grow to the point where they can compete with yams for soil nutrients. On the other hand, clean cultivation increases the risk of erosion. A protective mulch is particularly useful in such situations.

Even in African yams that sometimes produce seed, plantings are always made with seed tubers. The use of tubers makes control of the type of cultivar possible but of course reduces the quantity of tuber available as food.

Four kinds of planting material can be distinguished (fig. 7). Small, whole tubers produced after the harvest of the principal tuber are ideal seed tubers. Unless they are cut, they tend to germinate uniformly and be free of rot. However, unusually small secondary tubers are often produced by plants infected by virus diseases. The production of good secondary tubers as seed requires a preliminary evaluation of the foliage of the original plant.

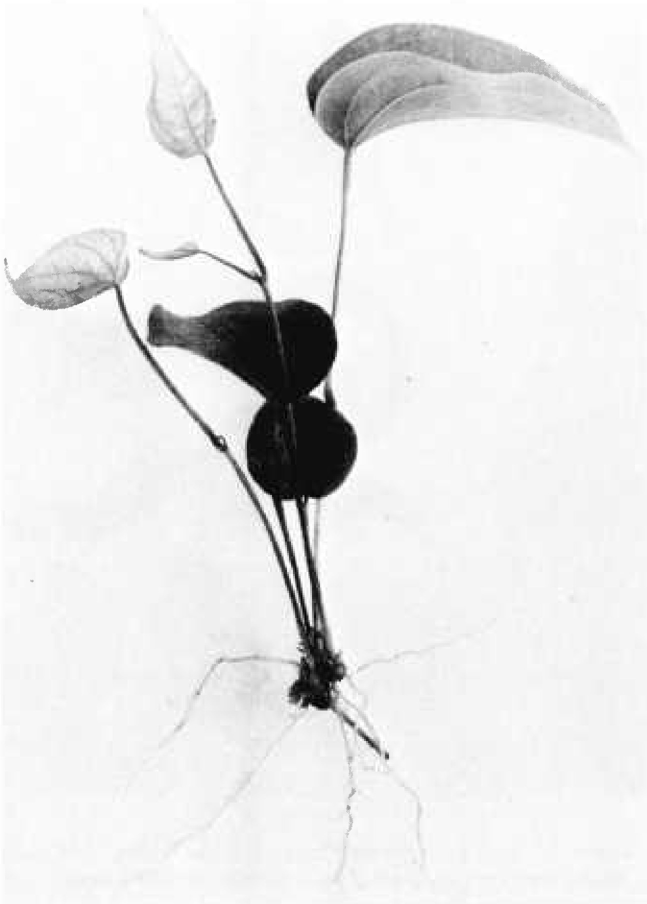

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FIGURE 8.—Rooted stem cutting of *D. rotundata*.

Only healthy plants should be selected as sources of planting material.

The crown or head piece of large tubers is also excellent planting material. Tips of the tubers (tails) and midsections are also good planting materials, but because they lack preformed buds, are slower to sprout than are head pieces and whole tubers.

Tubers to be cut for planting should be selected at harvest. Such tubers should be large, true to type, and free of insect damage. They should be stored at cool temperatures, protected from the sun, and inspected periodically. Tubers are normally cut to size (100 to 500 grams) and allowed to dry 1 or 2 days before planting. Small pieces yield proportionately greater tubers per unit of weight than do large pieces, but large tuber pieces are usually planted to obtain large individual tubers. Wood ashes have been used successfully in Puerto Rico to protect the cut surface from rot and are recommended here. Tubers should not be allowed to develop significant numbers of sprouts before planting. Removal of sprouts reduces vigor of future sprouts and although necessary at times, can hardly be recommended. The best practice is to cut tubers into seed pieces when sprouting just begins.

D. rotundata may also be propagated from stem cuttings (fig. 8). New stems are cut into sections with two leaves at one node and a portion of the stem on either side of the node. The cutting is sometimes treated with a hormone to induce rooting, and the stem portion is buried in sand, gravel, or other rooting medium. Intermittent mist spray is used to prevent moisture loss until rooting occurs. Roots are formed from an undifferentiated tissue, the primary nodal complex that forms at the axil of the leaf. From this tissue the stem and the tuber emerge later.

Cultivars of *D. rotundata* vary in their response to rooting from cuttings. Some root readily and some are stubborn. Furthermore, the fact that roots develop does not mean that shoots or tubers will form later. Depending on the cultivar, a variable proportion of cuttings do not develop into entire plants within a reasonable time. The technique, therefore, needs more intensive study before it can be recommended. At the present time it is useful chiefly as a method of multiplying a desired plant rapidly.

Optimum planting distances depend on many factors. The minimum distance between plants is 1 meter, but conventional mounds are difficult to construct at such a small distance. Mounds are usually about 2 meters apart. Ridges are spaced from 1 to 2 meters. Maximum size of tubers is obtained when plants are 2 meters apart. Closer spacing up to 1 meter results in decreased tuber size but more yield per unit of area. In addition to these considerations, the size of the planting piece can be smaller when planting distances are reduced.

After planting, sprouting proceeds at a pace relative to the kind of materials used, the size of the seed piece, the planting date, and the weather. Seed pieces need some moisture to germinate, but excessive moisture can lead to rotting of the tuber pieces. Appropriate moisture speeds germination but cannot completely overcome dormancy if the tubers are planted too early. On the other hand, sprouting occurs at the appropriate time of the year whether or not tuber pieces are exposed to appropriate conditions. The optimum time for planting is thus something between extremes—not too early, but before sprouting occurs. The time necessary for sprouting when tubers are planted just before natural sprouting occurs varies from 2 to 10 weeks.

Chemicals have been used to stimulate sprouting of tubers of other yam species. However, these have not been tried with

D. rotundata and *D. cayenensis*. Dipping tubers of other species 5 minutes in an 8-percent solution of ethylene chlorohydrin in water stimulates sprouting. Similarly, ethephon, an ethylene-releasing substance, is used at concentrations as low as 0.2 percent in water as a 5-minute dip. Both substances reduce sprouting time from 1 to 2 weeks and increase sprouting uniformity.

The formation of the sprout has been studied in some detail by Onwueme (*23*). Larger tuber pieces sprout more rapidly and give rise to more shoots than smaller pieces. In tuber pieces that do not include the crown, an inactive meristematic layer close to the tuber surface is stimulated to rapid cell division and gives rise to new buds. The buds are protected by a white calluslike tissue from the same meristem. This is ruptured by stem growth. Externally, sprouting loci appear as swellings on the upper surface of the tuber. Sprouting may proceed very rapidly in tuber pieces cut near the normal sprouting time.

Fertilization

For optimum growth of *D. rotundata* and *D. cayenensis* well-composited organic material mixed with the soil is desirable. Under such conditions, mineral fertilizers have sometimes caused reduced yields. The effects of organic materials are probably multiple: improved soil texture, improved nutrient availability and retention, and improved aeration and water availability.

However, in most instances organic material is not available. Furthermore, population increases in areas where slash-and-burn practices are traditional are gradually eliminating the practice of permitting used lands to lie fallow 5 years or more. Therefore, it is becoming necessary to add mineral fertilizer to the soil to compensate for loss of natural fertility. The problem is that the needs of the African yams for fertilizer are not well known.

The newly developing shoot is sustained by food reserves of the tuber, and therefore few or no additional nutrients are needed during its first weeks of growth. As these reserves are exhausted, yams need large quantities of nitrogen to stimulate vegetative growth. Later, as the plants turn from foliage to tuber production, potassium becomes the limiting element. Yams appear to be very efficient in extracting phosphorus from the soil and seldom need added quantities. Very little is known about yam requirements for minor elements, but significant yield improvements were obtained after addition of about 1 metric ton of magnesium oxide per hectare to the soil in Puerto Rico.

In one of the best experiments in this field, Koli (*14*) has shown that in Ghana application of 67.2 kilograms per hectare of nitrogen increased yields 22 percent, phosphorus at 33.6 kilograms per hectare increased yields 3.6 percent, and potassium applications did not affect yields. Koli pointed out the discrepancies among experimental results of other investigators and concluded that the application of organic material or nitrogen increases yields. These results suggest that fertilizer requirements vary from place to place and require local study for best results. The addition of fertilizer in two or three applications in place of a single application at the time of planting has proved beneficial in Puerto Rico.

Mineral fertilizer formulas used or recommended in the literature included 1 ton per hectare of 5-10-10 in Puerto Rico, a prohibitive rate in view of the price; 90 kilograms per hectare each of N, P_2O_5, and K_2O in Ghana; and 60, 120, and 60 kilograms of these chemicals per hectare in Brazil.

Pest Control

Research in various parts of the world has shown that chemical pesticides effectively control certain pests in yam plantations. Most countries regulate the use of pesticides and establish the amount of pesticide residues permitted on raw agricultural commodities, including imported commodities. (In the United States, the Environmental Protection Agency is responsible for this activity.) In the following discussion mention of a particular pesticide should not be construed to mean that its use on yams is legal in the United States or in any other country, or that residue tolerances have been established. The reader is cautioned to determine the status of every pesticide in the country where it is to be applied and to consult the appropriate authorities of an importing country concerning permissible residues.

Weeds

After planting, weeds will normally be a problem. Unless weeds are controlled, vigor of the yam plants will be severely reduced. Therefore, weed control measures should begin as early as possible.

Weed control should begin even before planting. Care should be taken that mulch or organic material does not introduce weed seeds. In addition, the preparation of land just before planting avoids the establishment of vigorous weeds even before sprouting occurs. Relatively late planting results in earlier and more uniform germination and thus reduces the chance that yams will be dominated by weeds. When materials are available and cheap enough, a mulch applied after planting may be the best weed control.

As soon as planting is finished and the ground is wet by rains or irrigation, a pregermination herbicide can be applied. The problem is to find a safe, effective herbicide. Frequently, a small

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FIGURE 9.—A plant of *D. rotundata* with mosaic disease in extreme form.

amount of damage to the seed pieces is tolerated in exchange for good control of weeds. Several preemergence herbicides have been recommended. In Trinidad atrazine[3] has been used at 3 kilograms per hectare. Ametryn[4] at 3 to 4 kilograms per hectare has also given good results. In any particular locality, herbicide use should be tested before recommendations are made.

After the effects of preemergence herbicides have worn off, weed control is usually achieved by spot application of a contact herbicide or by hoeing. The roots of yams are very shallow, and cultivation should be done with care. Once the vine is well established, it may shade most weeds sufficiently to prevent their growth.

Insects and diseases

Although *D. rotundata* and *D. cayenensis* are fairly free of pests and diseases, a few serious conditions do occur. These may drastically reduce yields.

The most serious of these diseases produces symptoms that suggest a viral agent. Called the green-banding virus (*26*), or mosaic disease in Puerto Rico and shoestring disease in Africa, the disease produces symptoms of mosaic—blotching, crinkling, distortion of leaves, and in its extreme phase, reduction of the leaf to a thin twisted sliver (fig. 9). As symptoms become severe,

[3] 2-Chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine.
[4] 2-(Ethylamino)-4-(isopropylamino)-6-(methylthio)-*s*-triazine.

yields decrease significantly. A viruslike particle has been found associated with the so-called Puerto Rico yam mosaic (*15*).

The mosaic disease of the yam tends to increase in incidence in any given field or area of production. Studies in Puerto Rico with sapogenin-bearing yams have shown that aphids may carry the disease. In the absence of insect vectors, natural spread seems to be slow. Nevertheless, continuous vegetative propagation without selection appears to influence greatly the severity and spread of the disease.

The most important factor in control of mosaic disease is the elimination of diseased plants. As soon as a new planting is well established, diseased plants should be dug up and burned, especially if the field is going to be used as a source of planting material.

The second important factor in control of mosaic is the selection of healthy seed tubers. It is a common practice in propagating yams to use small tubers from the previous harvest. Since small tubers may be the result of disease, their use tends to increase disease incidence. Large, healthy, undamaged tubers are the best sources of seed material. By selection of such tubers, disease incidence has been reduced after two seasons.

A second serious disease, especially in *D. rotundata,* is anthracnose. Widely occurring, it varies strongly in incidence from year to year, place to place, and among varieties. The disease is stimulated by wet conditions, especially dew during the night, and by high temperatures and sunlight during the day. The spores are disseminated by wind and by acervuli on stems or tubers. Seen as a black spot that enlarges quickly on leaf or stem, followed by yellowing, wilting and leaf loss, and in severe cases by death and dieback of the stem, the disease is caused by the fungus *Colletotrichum stoesporioides.* Other fungi may become involved as secondary pathogens. Zineb[5] and ferbam[6] applied as sprays each 10 days are partially effective in disease control. However, such treatment is costly. More satisfactory results are obtained through the use of resistant varieties.

Nematodes, especially species of *Prathylenchus, Meloidogyne,* and *Scutellonema,* are common pests of yams. Attacking the tubers, they leave unsightly burrows or swellings that reduce the usability of the tuber tissue. Furthermore, nematodes have been associated with tuber decay, especially with dry rot, a serious problem in harvested yams. To control nematodes, appropriate soils are desirable, especially heavier clays that do not favor their growth. Seed pieces can be cleared of most nematodes by hot

[5] Zinc ethylenebis[dithiocarbamate].
[6] Ferric dimethyldithiocarbamate.

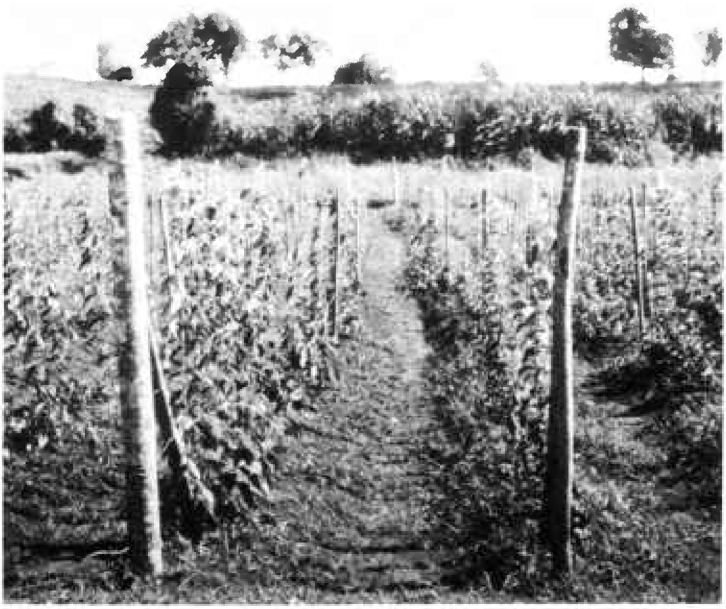

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FIGURE 10.—A pole, wire, and string system for supporting yams.

(50° C) water treatment for 30 to 60 minutes (*2*). Treatment of the soils with DBCP[7] at the rate of 28 to 112 kilograms per hectare has been useful in Nigeria.

Severe damage to tubers of *D. rotundata* and *D. cayenensis* is caused by several kinds of grubs. These pests vary in incidence and species throughout the Tropics but are especially bad in Africa. *Eteroligmus meles* (Billb.), the greater yam beetle, passes through its mating and reproductive cycle in swampy areas but migrates to yam plantations for feeding. In Puerto Rico the white grub, *Lachnosterma* sp., and *Diaprepes abbreviatus* often damage tubers. Although beetles have been controlled by application of insecticides to the soil, this is a risky practice. Insecticides can be leached from the soil and contaminate water supplies, and they can be ingested when the yams are eaten. Avoidance and sanitation are preferable techniques.

Rotting, closely associated with harvest injury, is the chief cause of tuber loss in storage. It may be substantially reduced by careful harvest and handling of tubers and by separation of injured and uninjured tubers, with injured tubers being used first. Warm, dry temperatures and aeration after harvest stimulate healing of wounds and reduce subsequent rot. Tubers should not

[7] 1,2-Dibromo-3-chloropropane.

be stored in piles or in damp situations, as these conditions increase rotting. Rotting is also associated with insect damage and nematode infestation, and control of these pests greatly reduces loss in storage.

Various organisms are associated with rot, and these vary from region to region. The principal organisms in West Africa are *Botryodeplodia theobromea, Rhizoctonia solani,* and *Fusarium oxysporum. Penicillium oxalicum, Aspergillus niger,* and various other organisms have also been found. Soft rot of seed pieces can be controlled by dipping them in benomyl[8] or thiabendazole[9] at 500 to 1,000 parts per million in water (*20*). The tuber pieces should be planted directly after treatment. Although the same fungicides help control rot in storage, *they should not be used if tubers are to be eaten later.*

The treatment of tubers, especially their young tips, with indoleacetic acid reportedly reduces storage rot, even when yams are piled, but these results could not be repeated in trials in Nigeria. The common treatments with wood ashes or lime, are simple, useful methods on the farm.

Staking

Some kind of support (fig. 10) is usually required for good production of yams. *D. rotundata* and *D. cayenensis* are sometimes grown without support, but the sacrifice in yield is so great that only dire shortages of labor or staking material should prevent staking.

The staking system should be built of local materials. Crude sticks or branches, slim bamboos, or bamboo side branches are often used. Sometimes dead materials from previous crops such as corn, sorghum, or tobacco are used, but these usually do not last long enough to give support through the growing season. The use of living plants is not recommended because they compete with the yams and severely reduce yields. Nevertheless, because the staking of yams is so costly, further attempts to develop a living-plant system, especially with legumes such as *Cajanus* and *Sesbania,* should be made.

One of the best staking systems yet designed is described by Wholey and Haynes (*30*). Twelve-foot teak poles are strung with 12-gage galvanized wire 6 to 8 feet off the ground and tied to stakes driven into the ground. Two rows of yams are planted, one on each side. When the vines have developed sufficiently, strings are tied to them and passed over the wire. Access to the planting is provided by furrows equidistant between poles. In a variation of

[8] Methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate.
[9] 2-(4-Thiazolyl)benzimidazole.

the technique, a lower wire is also used, and strings are passed between the two wires.

Vines should normally be grown in full sunshine; indeed, their climbing habit tends to assure them a place in the sun. For best yields yams should not be planted under trees or in shade.

Harvests and Yields

Perhaps the most important characteristic of *D. rotundata* is not the one which West Africans appreciate, the sticky quality of the cooked tuber that makes the preparation of fufu possible, but the suitability of most cultivars for double harvesting. Unique among yam species in this property, *D. rotundata* bears twice because of its adaptation to short rainy seasons.

Whereas the onset of the first harvest is determined by digging around the tuber and deciding when it is large enough, that of the second harvest is shown by senescence of the foliage. In the Northern Hemisphere this occurs from October until January and is dependent on rainfall. Early senescence is sometimes associated with leaf-spot diseases or stem wilt, but it appears that dieback normally begins before disease conditions become severe.

As soon as dieback occurs, the tuber can be harvested. However, if the tuber has been growing rapidly, the growing tip will not be well protected with bark. If left in the soil several weeks, the bark will develop (at the expense of the flesh, of course) and the tuber can then be stored with less risk.

Harvest is usually managed with digging sticks, knives, or spades. It is easy to open the mound structure and remove tubers. Vines, stakes, and possibly other plants intercropped with the yams and on the same mounds are left undisturbed. Later, the stakes are sometimes removed for use in new plantings. Once harvested, it is important to remove tubers from the sun, as exposure predisposes them to rot in storage.

The components of yield are tuber size, tuber number, number of plants per unit of area, and in certain varieties the ability to regrow after a first harvest. Complete crop failures are unusual, even when virus or leaf-spot diseases are present.

The size of the individual tubers varies considerably, but few exceed 5 kilograms. In contrast, *D. alata* varieties have produced 50-kilogram tubers. Although *D. rotundata* has not been studied in detail with respect to the production of giant yams, its potential seems to be limited.

Most reported African yam yields are low when compared to those of the chief competing species, cassava, and those of Asian yams. Coursey (*8*) summarized yields for Africa as 7.5 to 18.0 metric tons per hectare. In the West Indies yields are usually higher, about 15 to 25 metric tons per hectare. Since the tubers are about the same size, yield differences may be due to differences in plant spacing. The highest yield reported in Puerto Rico for *D. rotundata* is 67.3 metric tons per hectare, a yield of healthy tubers grown in a friable clay soil without plowing or construction of mounds (*6*). Most reported yields are considerably less than should be expected under improved agronomic conditions, especially the elimination of diseased plants and the use of high-quality seed tubers.

The distribution of yields among early and late harvests varies. In some cultivars the early harvest yields more than the late harvest, but this depends chiefly on variety and time of harvest.

Interesting differences can be seen when *D. esculenta, D. alata,* and *D. rotundata* are grown together. The yield of *D. alata* cultivars is often double that of *D. rotundata* and *D. cayenensis. D. esculenta* yields are variable, but under good conditions are better than those of any other species.

STORAGE

The best data on yam storage concerns *D. rotundata.* This yam, and to a lesser extent *D. cayenensis,* is stored more frequently for long periods and constitutes an important staple for a large number of people.

Good storage practice begins in the field. During the dry season, tubers can be left unharvested in the ground without appreciable loss of quality. Although they will lose weight, mainly from respiration and to a lesser extent from dehydration, the advantages of field storage outweigh such losses. However, tubers stored in the field are subject to damage by beetles, rats, and pigs, and of course, the depredations of human beings. It is perhaps because of the latter that tubers are normally harvested for storage. After harvest, tubers should never be left in the sun or rain as both increase susceptibility to rot.

Storage facilities vary among farmers and throughout the yam-growing region. It is common enough to find tubers stored in pits, in piles, or on the ground under houses, but more sophisticated structures, yam barns, are also used (fig. 11). A yam barn is a shed with woven-stick walls and a thatched roof. In the barns the individual tubers are tied to walls. The tubers being separated and surrounded by air, storage rot is minimized.

Coursey (*7*) has shown that *D. rotundata* tubers store better than those of *D. cayenensis,* as would be expected from the differing lengths of their growing seasons. The principal causes of loss are respiration, desiccation, and rotting.

The most effective protection against storage loss is selection

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FIGURE 11.—Yams stored in a yam barn.

of sound yams. Damaged tubers should be used as soon as feasible or converted to flour. But even apparently sound yams are susceptible to rotting if they have been damaged by insects and nematodes.

Although fungicides protect yams from deterioration, they are a health risk for humans and should be restricted to treatment of seed tubers. On the other hand, washing with lime or dusting with wood ashes are simple treatments that effectively reduce rot.

Tubers of *D. rotundata* have been stored in Puerto Rico for a full year (*25*) at 16° C and 80 percent relative humidity. Tubers begin to sprout, but sprouting never advances beyond the production of a "button." Storage below 10° to 12° C may lead to the development of what Coursey calls "chilling damage" (*9*). After a few weeks at low temperatures permanent physiological damage is done. When returned to normal temperatures, rapid internal breakdown occurs: tubers become watery and develop objectionable odors.

In Puerto Rico breakdown at normal or ambient temperature has been seen. After 3 or 4 months the bark of the tuber becomes watery and tends to loosen from the underlying parenchyma. The quality of the flesh is also lowered. Except when refrigeration with humidity control is available, the maximum storage life of *D. rotundata* tubers is 4 months and of *D. cayenensis*, 2 months.

CULINARY CHARACTERISTICS

Although the tubers of *D. rotundata* and *D. cayenensis* are somewhat large for home use, they are generally fairly smooth and lack awkward appendages. When produced in rocky or hard soils, tubers are often misshapen. Loss during peeling and preparation for the kitchen is minor. After cutting tubers into thick slices, the bark may be peeled off readily with a knife. The cut surface of a large tuber should be exposed to dry air, which will effect temporary healing. It is also possible to protect the cut surface with a piece of wax paper or plastic wrap.

Sticky proteinaceous gums exude from cut tubers, but their stickiness is not related to that of cooked flesh. In addition to gums, tubers exude a rich mixture of other substances, including phenolic substances that may easily oxidize. The oxidation of an amine catechin is believed to be responsible for the brown or blackish spots found on cut surfaces. The complex browning reaction requires the presence of oxygen, the catechin, and an enzyme, and is avoided by the elimination or inactivation of any of the three requirements. The use of cellophane or wax paper on cut surfaces reduces oxidation. Varieties subject to frequent or extreme oxidation are best avoided because of their unappetizing appearance.

Polyphenolic oxidation varies among cultivars but is more common in old or injured tubers. The bitterness often associated with oxidation appears rather to come from leucoanthocyanidin content. The cut surface of some yams contains calcium oxalate crystals which may sting the skin, a harmless sensation that disappears in about 30 minutes.

The yellow color of most *D. cayenensis* tubers is due to carotenoids, including beta carotene, and numerous xanthophylls and their esters. Anthocyanin coloration is not found in tubers of these African species.

The flesh of a newly cut tuber appears ricey or stringy because of accumulated starch around the vascular bundles. The characteristic is preserved through cooking and gives a pleasant texture and appearance to the product. The actual amount of fiber in the tuber is quite low, and fiber does not constitute an obstacle to appearance or the palate.

Individual varieties are seldom recognized by taste except by the most acute observers. Nevertheless, there are recognizable differences, and thus certain varieties are preferred for eating. When cooked tuber has an acceptable appearance, it invariably is also appetizing and flavorful.

COOKING AND COOKED PRODUCTS

The most important use of *D. rotundata* is as fufu, a native African dish. Preparation begins by peeling and cutting tubers into small pieces. They are boiled until soft, drained, and then pounded in a mortar with pestle until a stiff, glutinous dough is formed. The dough is molded into a ball and served. Diners remove portions of the dough with their fingertips and dip them into a stew (*8*). Fufu is extremely popular throughout West Africa, where it is made not only from yams but from other starchy foods, such as cassava, plantains, and cocoyams.

Yams are also boiled. They may be served in pieces or mashed, alone or with a sauce or gravy. In soups or stews, pieces may be used, or mashed yam may be added as a thickener. Mashed yam may also be formed into cakes and fried.

Yam tubers may be cut into thin slices or strips to be cooked in the style of potato chips or french fries (*18*). However, not all cultivars are suitable for this use because frying produces a bitter flavor.

Instant yam flakes are prepared by peeling, cooking, mixing in a slurry, and drum drying (*12*). The flakes can be stored for long periods and reconstituted by adding hot water or milk. The product is highly acceptable, but quality depends on the use of appropriate cultivars. Some *D. rotundata* cultivars are good for this purpose, but *D. cayenensis* is not recommended because of its yellow color.

An interesting alternative to yam flakes is yam flour, which is made by grinding cooked, dried tubers. The technology is reported by Jarmai and Montford (*13*). The flour can be stored for long periods and used to make fufu and mashed yam. It may also be substituted for part of the wheat flour in baking bread and pastry. *D. alata* has been studied more extensively in this respect than *D. rotundata,* but the latter is probably the most used. Better home and factory methods are needed both for the preparation and the use of the flour, as this could constitute an effective way to utilize yams through the entire year.

COMPOSITION

The dried weight of the edible portion of the tuber varies from about 13 to 36 percent of the whole-tuber weight. Tubers from the first harvest of *D. rotundata* usually have low dry weights. The mature tuber of most cultivars is quite dense. Density, however, is a varietal as well as a physiological trait.

The major part of the dry weight can be accounted for by starch, which varies, with the dry weight, from about 10 to 28 percent. In addition to starch, the dry weight includes cellulose or fiber, about 9 percent; protein, about 5 percent; sugars, 2 to 3 percent; and fatty materials, less than 1 percent.

The starch of *D. rotundata* and *D. cayenensis* is rather coarse (*22*). The individual granules are large and triangular, the average measuring 10 to 70 micrometers in length. In addition, a typical starch preparation contains a very large number of very fine grains, but these make up a very small percentage of the starch present. The grain size is large for any root and tuber and many times larger than the average starch grain of *D. esculenta.*

The amylose content of the starch is about 20 to 26 percent, similar to that in *D. alata,* cassava, and several other roots and tubers, but much higher than that in *D. esculenta. D. rotundata* starches produce a gel that is highly viscous (necessary for fufu production) but low in tensile strength. Pasting temperature is about 76° C, low compared to other yam species.

No special uses of *D. rotundata* and *D. cayenensis* starches have been found, and in fact the starch is seldom extracted.

The few analyses made so far show the protein content of both species to be about 4 to 8 percent, somewhat lower than that of *D. alata* and *D. esculenta* (table 5). The amino acid spectrum of the protein is fair. Lysine content tends to be high, and sulfur-containing amino acids low, as compared with the FAO reference protein. Tryptophan content (not measured in the cultivars listed in table 5) is low, from 10 to 30 percent of the FAO standard.

The vitamin C content of *D. rotundata* and *D. cayenensis* is sufficient to make these species fair sources, but is slightly higher in *D. rotundata* (6.5–11.6 mg/100 g) than in *D. cayenensis* (4.5–8.2 mg/100 g), according to Coursey (*8*). On the other hand, provitamin A (beta carotene) occurs only in the yellow forms, mixed with other carotenoids (*19*).

Not enough work has been done on the nutritive composition of the African species. During the process of selection or the

TABLE 5.—*Essential amino acids and total protein in* D. rotundata *and* D. cayenensis *cultivars compared with FAO reference protein*

[Grams amino acid per 100 grams protein]

Protein component	FAO reference protein[1]	Cultivar			
		'Negro'	'Guinea Blanco'	'Saint Prix'	'Akandu'
Amino acids:					
Valine	4.2	4.6	4.6	4.8	5.1
Isoleucine	4.2	4.2	4.2	4.3	4.0
Leucine	4.8	7.6	7.7	8.0	7.4
Threonine	2.8	3.9	4.3	3.9	4.3
Methionine	2.2	1.5	1.9	1.4	1.4
Crystine	2.0	.1	.7	.0	.4
Phenylalanine	2.8	6.1	6.3	6.2	4.8
Tyrosine	2.8	2.8	3.2	3.0	2.0
Lysine	4.2	5.4	5.5	5.6	4.7
Total protein[2]	...	5.1	6.7	7.5	5.6

[1] FAO Nutritional Studies 24 (*11*).

[2] Grams per 100 grams of yam tuber.

breeding of better cultivars, it might be possible to increase the content of vitamins, total protein, and sulfur-containing amino acids to enhance the food value of these yams.

POTENTIAL USE

It is still unclear whether the relatively limited distribution of *D. rotundata* and *D. cayenensis* outside West Africa is associated with particular characteristics of these species or with the competition of other species. Surely, *D. alata* is an easier species to grow: the African species are not lazy man's food. But it is also highly probable that the limited use of African yams is associated with a lack of introduction and distribution. Probably haphazard distribution by casual visitors accounts for the principal distribution achieved. Most introductions probably died out, and it is surprising, therefore, to find superior standard cultivars in Puerto Rico, Jamaica, and Brazil.

The *D. rotundata* and *D. cayenensis* germplasm in Africa is so diverse that it is extremely difficult to select a few really superior varieties. Trials will be necessary in many regions. Since yam growing is closely associated with customs and culture, one cannot expect that the favorite variety of one region will automatically gain acceptance in another.

Preliminary experience in the introduction and distribution of African yam varieties suggests that most, if not all, are affected by mosaic virus. It is still uncertain whether this disease is a hazard for other yam species, but it appears to be widely distributed already. As attempts are made to utilize the African yams in new areas, it will be necessary to watch the virus situation carefully. If current attempts to rid varieties of virus through meristem culture are successful, introduction should be safe and profitable.

In West Africa the culture of yams is still highly viable even though cassava, rice, and cocoyams compete with and have displaced yams to a great extent. While it is impossible to think of West Africa without yams, they may play a smaller role if acreages continue to decrease. This trend is regrettable, for the West African yams are a food resource meriting preservation and development.

Because the evolution of yams has not been guided by principles of plant breeding, the potential for rapid advancement by breeding has not yet been demonstrated. It has been assumed that conventional breeding was impossible because of lack of flowering and fertility. The development of freely flowering, fertile populations and the ease of production of countless seedlings suggest that for the first time an important species can be improved by modern techniques (*28*).

Among the factors that now limit the African yams are their relatively poor yields and susceptibility to virus disease. It may be possible to change these characteristics by breeding and by improved culture. It is encouraging to see study being devoted to the African yam in recent years, and scientists may well be able to make the necessary breakthroughs.

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