TROPICAL YAMS AND THEIR POTENTIAL

Part 3. *Dioscorea alata*

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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 processed 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 third 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 U.S. Agency for International Development to introduce, evaluate, and distribute better yam varieties.

CONTENTS

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TROPICAL YAMS AND THEIR POTENTIAL

Part 3. *Dioscorea alata*

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INTRODUCTION

For many people in the world the word "yam," or its translation, refers to *Dioscorea alata* L., the most widespread yam species. It has been introduced to all parts of the Tropics where growing conditions are suitable, and it has frequently gone wild and continued to develop new variations. It has become accepted in West Africa, where it now sometimes competes with two important native species, *D. rotundata* Poir. and *D. cayenensis* Lam. It is difficult to say whether or not the total production of *D. alata* surpasses that of its chief rival, *D. rotundata*. Whereas the latter is almost restricted to West Africa, *D. alata* is so widely distributed that it is impossible to give an accurate estimate of production, but it cannot be less than 10 million metric tons per year. Its agronomic flexibility, widespread occurrence, ready acceptance, and high nutritive value suggest that *D. alata* is the most important of the cultivated species. Furthermore, it has great promise for the future, especially when improved varieties are distributed. Those already discovered are among the best yams in the world—in flavor, processing quality, production, and agronomic characteristics.

History and Origin

In spite of its importance, the little that has been written about the origin of *D. alata* is mostly speculation. That great numbers of varieties are known from India to the islands of the South Pacific, many of which are quite local in distribution, suggests that the species was domesticated and widely distributed very early. Furthermore, the occurrence of distinct but closely related varieties on somewhat isolated islands suggests that it has continued to evolve in areas where it has been introduced.

De Candolle (*8*)[2] hypothesized an Indo-Malayan center of origin for *D. alata,* based on the widespread varieties found there. Burkill (*4*), a superb student of the yam, placed the origin of the species in Southeast Asia and attempted to trace its distribution throughout the world and gradual decline in importance as cassava, sweetpotatoes, and potatoes displaced it. The existence in Burma

[1] Formerly, Federal Experiment Station.

[2] Italic numbers in parentheses refer to items in "Literature Cited," page 38.

of two closely related wild species, *D. hamiltonii* Hook and *D. persimilis* Prain et Burk., suggested that *D. alata* had been selected from these or from their hybrids. Both are characterized by long, deeply buried tubers that superficially resemble some cultivated but inferior varieties of *D. alata*. Burkill hypothesized that deep tubers evolved as a protection from wild pigs and that human selection resulted in the short-tubered, compact varieties. For varieties with upward-curving tubers, which eventually push their way out of the soil, he hypothesized another human selection, since this growth habit makes harvesting easy.

There is little evidence elsewhere to support Burkill's hypothesis. Wild species related to *D. alata* are also found in Papua New Guinea. Moreover, the variation in *D. alata* is enormous, and some varieties are unique to the region. Indonesia also has extremely diverse varieties that must have existed for centuries.

Relying on what is known about historical movements of people in Southeast Asia and on the scanty information about distribution and variation in yams, Alexander and Coursey (*1*) placed the origin of *D. alata* in an area lying between the distribution of *D. hamiltonii* (East India and West Burma) and that of *D. persimilis* (Indochina). The difficulty of their theory is that cultivated races in this area (roughly Burma) do not include many examples of the short-tubered, compact types found in Indonesia (especially Celebes) and Papua New Guinea.

It is highly likely that simple or primitive forms of an initial species, perhaps well distributed, were selected locally to give rise to the principal varietal types. This could have happened independently on widely separated islands. Interchange and hybridizations increased variation. Inspection of varieties from worldwide sources suggests to the present author that at least two distinct species were involved in the evolution of *D. alata*, in one of which the stem was not winged; study of materials on hand is needed to clarify this problem. No systematic breeding now appears possible, and existing varieties appear to be ancient dead-end relics of the evolutionary process. A remarkable story of ennoblement of the species thus remains undisclosed.

Geographic Distribution

Dioscorea alata is a plant of the hot humid Tropics; it seldom occurs where cool temperatures or dry periods prevail during the growing season. There is no single area, however, where *D. alata* is the chief starchy food; it is almost always utilized as one of several farinaceous crops (other yams, cassava, sweetpotatoes, and aroids) that are used to some extent interchangeably.

In Southeast Asia *D. alata* is grown chiefly as a dooryard crop.

It is of special importance in Papua New Guinea, where more than 30,000 persons depend on yams for their livelihood (*19*). In southern India *D. alata* yams are grown and appreciated, but are secondary foods. They and other yam species are important crops in some but not all parts of Indonesia. In Malaysia yams are not common. In the Philippines few varieties of *D. alata* are found, but some of them are unique and highly valuable. Many varieties of *D. alata* are found throughout the South Pacific islands, and the species is important, but more so on some islands than on others.

Dioscorea alata has had to compete with native species of yams in West Africa, where it has become a second or third best yam. Varieties of *D. rotundata* and *D. cayenensis* are usually preferred because they can be pounded to produce the typical dish of the region, a sticky dough called fufu. There are few areas where *D. alata* is unknown, however, and in Sierra Leone *D. alata* outranks *D. rotundata* in importance. Almost everywhere it is known as water yam, or the equivalent in local tongues. The slight variation among African forms suggests that only a few varieties, and certainly not many superior ones, have been introduced. Elsewhere in Africa, *D. alata* is even more poorly distributed and not of great importance. Feral varieties are known in Africa.

In the New World, introduced *D. alata* varieties are found chiefly in the Caribbean, the north shores of South America, and in scattered locations throughout Central America. In localized areas and certain islands, especially Trinidad and Barbados, *D. alata* is of considerable economic importance. Isolation has undoubtedly played an important role in establishing varieties, for the principal varieties differ from island to island throughout the Caribbean.

In South and Central America *D. alata* is hardly known and poorly distributed except for isolated, usually coastal pockets. A few varieties were introduced in Brazil years ago, and recently others have been brought in. Introduced *D. alata* competes in some areas with introduced African species.

BOTANY

Ethnobotany

Although the culture of West African peoples has developed around the exigencies of the yam (*9*), in only one area of Southeast Asia—Papua New Guinea—has a similar phenomenon occurred. There, *D. alata* has religious and psychological importance much beyond its significance as a food crop. The planting of yams in two types of gardens has been described by Lea (*19*). Whereas in one type of garden yams are produced for food, in the other they are treated with elaborate care to produce enormous tubers. Planting of the ceremonial gardens is done only by men and boys and is regulated by numerous taboos. Great pride and masculinity are attached to the production of giant yams. Although the techniques for production of such yams have passed to other islands of the South Pacific, little or no special significance is attached to their culture outside of Papua New Guinea.

Classification

There are perhaps thousands of *D. alata* varieties. They differ especially in characteristics of the tuber and often in characteristics of the foliage. This polymorphism has led to attempts to divide *D. alata* into several species or subspecies or to group varieties into meaningful categories. (See "Varieties".) Such attempts have not been successful, but have confused the literature with useless synonyms such as *D. atropurpurea* Roxb., *D. purpurea* Roxb., *D. globosa* Roxb., *D. rubella* Roxb., D. *eburnea* Lour. or Willd., *D. vulgaris* Miq., *D. javanica* Queva, *D. colocasifolia* Pax, and *D. sativa* Del.

In many areas the common name "water yam" is applied to *D. alata*. It is not a good name, for it does not refer to any consistent property of the species. It is used, moreover, for individual varieties or groups of varieties of *D. alata*. Other common names are greater yam, Asian greater yam, winged yam, white yam, and ten-month yam, none of which is entirely adequate. A useful descriptive name might be Asian wing-stemmed yam.

D. alata belongs to the section Enantiophyllum, a section of the genus known only in the Old World, with many species in Africa and Asia. The Asian species, about 50, have been described by Burkill (*5*). Tubers of this section usually grow vertically, and the leaves are simple. The section includes many edible species. Only *D. persimilis* and *D. hamiltonii*, previously mentioned, appear to be closely related to *D. alata*, and only these three species have winged stems. The section also includes the principal African species, *D. rotundata* Poir. and *D. cayenensis* Lam.

In common with other yams, the wing-stemmed yam belongs 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 (*18*). The family is characterized by rhizomes, usually reduced to a nodeless structure. The male and female (fig. 1) flowers, usually on separate plants, are small and often inconspicuous. The inferior ovary becomes quite prominent after fertilization. The floral pattern is based on sets of three.

Morphology

All varieties of *D. alata* seen by the author can easily be recognized as belonging to this polymorphic species, and varieties of other spe-

PN-4437

FIGURE 1.—Female flowers of *D. alata*.

cies can usually be excluded readily. *D. alata* is a glabrous vine that climbs by twining to the right. The length of the vine varies from 2 to 30 meters or more in primitive forms.

The fleshy stems are characterized by wings, typically membranous and often ruffled. In some varieties the wings are reduced or almost absent, but the stems may be quite thorny, in which cases the thorns occur in straight lines representing the wing; the habit is associated with two distinct tuber types and with a distinct leaf shape. In rather primitive varieties with well-developed wings, the wings of the thickened basal stem are often modified into thick, blunt thorns quite different from the thorns of the Feo type. Wings are believed to help the stem grasp smooth objects in twining.

The leaves are often quite large, although those of the better varieties may be smaller. They are commonly opposite on the stem, but in a few varieties and on the young vigorous stem of most varieties, they are alternate. The leaves are glabrous, with a slight bluish bloom in a few varieties. Many varietal differences can be distinguished (fig. 2). The shape of the leaf is determined principally by the width of the sinus between the leaf lobes. Varieties differ in the folding and undulation of leaves, in the thickness of the lamina, in green color intensity, and in anthocyanin coloration. The wings of the petiole of the leaf are usually enlarged at the stem, producing a characteristic appearance. Stipules are rarely present.

The flowers of *D. alata* are produced during the last third of the growing season, when tubers are forming. Not all varieties flower, and some flower sporadically, perhaps in response to seasonal variations. It is unknown whether flowering can be induced by changing environment.

Male and female flowers are borne on different plants. The male flowers are small (1–2 millimeters in diameter) and are produced in crowded panicles that originate in the axils of the leaves and the tips of the branches. The sessile flowers range from green

PN-4438

FIGURE 2.—Representative leaves of *D. alata* varieties. (Two-fifths actual size.)

to white. All six stamens are well developed. In many varieties the male flowers do not open or open such a small amount that pollinating insects cannot enter. The pollen of most varieties, as seen under the microscope, is malformed or aborted, but a few varieties, especially of the wild or primitive type, appear to be functionally fertile. The female flowers (fig. 1) are borne on long racemes from the axils of the leaves. The flowers are characterized by a prominent trilocular inferior ovary from 8 to 15 centimeters long. The capsules, which develop rapidly after pollination, reach 20 to 30 millimeters in length. They mature, dry, and split along the sutures of the wings to release two seeds from each of the three locules. Few capsules are produced, however, even when male and female plants are grown together. Moreover, the developing capsules often contain only a single seed, and this frequently aborts before maturity. Thus, as in the case of males, most female plants are sterile. The author has no experience growing *D. alata* from seeds and believes that conventional breeding of this species would be extremely difficult.

Only newly germinated seeds have true roots; the roots of developing tubers are strictly adventitious, the tuber being nodeless and originating from the stem. The principal roots arise from what is sometimes called the primary nodal complex (fig. 3), or crown, of the plant, near the surface of the ground, but in some varieties, a variable number of roots arise from the body of the tuber itself. When stems touch moist soil they often develop adventitious roots and may even develop large tubers.

The tubers of *D. alata* are extremely variable, and the number of possible forms almost endless. Plants normally bear only one tuber, but two to five are common, even on varieties typically producing one tuber. These are normally

PN-4439

FIGURE 3.—Primary nodal complex of rooted cutting of *D. alata*, showing origin of roots and shoots. (Three times actual size.)

located vertically in the soil and usually descend. Unusual varieties are known in which, after growing down awhile, the tip of the tuber begins to grow upward, producing a long, thin, U-shaped tuber. Tubers often enlarge as they descend to form a pyramid, but they may also be constricted later in a spindle shape. Tubers of some varieties are extremely smooth, while those of others are extremely irregular. Shape is complicated by tuber branching, which may occur during early or late growth. There may be few or many branches, either the same size as the main tuber or smaller, and the branches may themselves continue to branch. Some of the most unusual shapes are found among the New Guinea yams, in which the tuber can occur as a series of vertical intersecting plants.

The tubers are renewed annually. A tuber produced one year gives rise in the next to a shoot, the growth of which is usually preceded by the appearance of the primary nodal complex from which roots, new tuber, and stem arise. The new tuber remains extremely small during the initial months of growth, but develops rapidly near the end of the growing season.

Many varieties also produce single or multiple aerial tubers (fig. 4) in the axils of the leaves at the same time underground tubers are being formed. Aerial tubers often resemble underground tubers in shape and branching habit. When they touch damp soil, they grow into it rapidly. In this way a single plant can give rise to many small, rooted tubers in a short time. Aerial tubers continue to be produced until foliage dies back at the end of the growing season. All are edible, but the smaller ones are immature and inconvenient to prepare for cooking.

Varieties are distinct with respect to flesh color. Anthocyanins color some flesh purple, usually irregularly. The flesh of varieties with no anthocyanin varies from white or cream to yellow. Unidentified carotenoids are among the pigments. Purple-fleshed varieties are favored over white in the Philippine Islands because of the agreeable color that they lend to desserts. Nevertheless, anthocyanins have no nutritional value, and in the opinion of many persons, distract from the appearance of the cooked tuber.

Both smooth- and coarse-textured varieties are found. Coarse tuber texture, which appears curdlike, is attributable to bundles of storage tissue in a somewhat clear matrix.

When a tuber is cut, the flesh exudes mucilaginous substances, now known to be glycoproteins, which can discolor the surface, slowly or rapidly, upon oxidation. Exposed to air, cuts are healed by the formation of layers of dead, dry cells. There is no evidence of suberin deposition in this species, but dried cells effectively reduce moisture loss and fungal penetration.

PN-4440

FIGURE 4.—Typical aerial tubers of *D. alata.* (One-half actual size.)

Cytology

Numerous counts have been made of the chromosomes of *D. alata.* All numbers reported, whether based on pollen-mother-cell or root-tip observations, are based on multiples of 10 (*21*). The occurrence of 2*n* numbers such as 30, 50, or 70 can only be accounted for through the hybridization of varieties with different numbers of sets of 10 chromosomes. Thus, polyploidy is normal in the species and probably accounts for its high sterility.

Variations in chromosomal number within the cells of a single variety have been reported (*28*). Such variation can be fixed by asexual propagation and in fact probably accounts for the occurrence of sibling varieties—that is, varieties that differ only in minor details. Odd chromosome numbers due to the presence of one or two extra chromosomes are uncommon, and such counts are not reliable. Aneuploidy, when it occurs, would contribute to the sterility of the species. Extra chromosomes have been attributed to a sex-determining mechanism. There is, however, no concrete evidence to suggest an X0 sex-determining system. Furthermore, Martin (*20*) has shown how polypoidy can explain the unusual sex ratios found in most species. Males predominate over females in most controlled crosses, in predictable ratios associated with numbers of sex-controlling chromosomes present.

As previously noted, male and female flowers are usually sterile, and in varietal collections seeds are seldom produced. No efforts to breed the wing-stemmed yam have been reported in the literature. It is difficult to escape the conclusion that existing varieties are very old and perhaps have diverged from their progenitor varieties by somatic mutation. Nevertheless, a sexual system must have been present at one time to have produced the variation exhibited by this species. Primitive man presumably practiced selection and gradually produced the fine varieties now known. It appears that this process of improvement is no longer possible.

VARIETIES

The variation of *D. alata* has been dealt with in several classifications. Roxburgh (*27*) divided *D. alata* into five species (see "Classification"), chiefly based on the anthocyanin coloration of tuber and foliage, but also on minor morphological features such as number of wings on the stem. The materials available to him apparently did not represent the full variation in the species. Ochse and van den Brink (*25*) set aside a group of highly improved varieties from a much larger, more heterogenous primitive group. Burkill, a careful observer who had an extensive Southeast Asian collection, based his classification on four kinds of tubers (*3*): long and deeply buried tubers, half-long tubers, short tubers, and nonburying tubers. He then broke each class into a number of subclasses based on characters such as branching tendency, presence of a neck, and tendency to curve. While his classification groups certain related varieties together, it is an oversimplification of the varietal picture and is useful principally in making rough order out of apparent chaos.

Gooding (*15*) developed a key to distinguish some West Indian varieties of *D. alata*. His system, though useful, cannot adequately deal with a large collection. Martin and Rhodes (*22*) studied the correlations among 100 characteristics of 30 *D. alata* varieties and found that certain tuber and foliage characteristics tended to occur together. Three groups of varieties were delimited: Feo (fig. 5), primitive, and choice. Feo was judged to be a natural grouping; choice, highly artificial; and primi-

PN-4441

FIGURE 5.—Irregular tubers of a Feo group yam. (One-fourth actual size.)

tive, intermediate. In another study Rhodes and Martin used the techniques of numerical taxonomy to define groups in a less arbitrary fashion (*26*). The primitive group was divided into two easily distinguished subgroups. In this study the difficulty of grouping was revealed by the special techniques used. On a multidimensional graph made possible by the principal-components method, few varieties were found to occur in recognizable clusters. The characteristics found by the authors to be useful in classifying varieties and their method of rating are given in table 1.

The classification of *D. alata* varieties into groups is probably always artificial and serves best the needs of particular investigators. The family tree of the species would probably consist of a network of anastamosing branches, a few small limbs, and many twigs now separated from the parental trunk. Thus, the bewildering array of varieties will probably continue to confound.

Although there is regional disagreement about what traits a good variety should have, the following characteristics would generally be considered desirable. The foliage should be vigorous, relatively resistant to leaf-spot diseases, and low in anthocyanin coloration. Tubers should be short, compact, uniform in shape, smooth skinned, and free of large roots. Flesh should be essentially free of pigments, low in oxidation tendency, and uniform, with a very fine granular structure. After cooking the color should be white or cream,

TABLE 1.—*Suggested characters for* D. alata *analysis*

Character	Method of rating[1]
Plant characters:	
Anthocyanin in old stem[2]	0 to 6.
Anthocyanin in lower petiole[2]	0 to 6.
Anthocyanin in upper petiole[2]	0 to 6.
Angle of basal veins	Estimated, 15° intervals.
Widest region of leaf	Observed.
Green color intensity of leaf	1 to 6.
Rugosity of leaf	1 to 6.
Development of spines	0 to 6.
Development of wings	1 to 6.
Petiole length	Measured.
Leaf blade length	Measured.
Width/length ratio of leaf	Calculated.
Presence of aerial tubers	0 to 2.
Tuber characters:	
Average weight	Weighed.
Type	1 to 5, solitary to multiple.
Shape	1 to 4, spherical to long.
Tendency to have neck	0 to 3.
Tendency to branch	0 to 5.
Site of branching	0 to 5, head to tip.
Length	Measured.
Diameter/length ratio	Calculated.
Pinkness of cortex, stem end	0 to 6.
Anthocyanin[2]	0 to 6.
Yellow color	0 to 3.
Tendency to oxidize	0 to 3.
Grainy appearance	0 to 3.
Sting of flesh	0 to 3.
Acceptability after cooking (appearance)	0 to 3, not acceptable to pleasing.
Erosion in cooking	0 to 3.
Flavor	1 to 3, poor to excellent.

[1] In the numeric scales indicating range of variation within a character, 0 designates none or not present and 1 designates lowest or least, unless otherwise specified.

[2] Judged by red color.

TABLE 2.—*Superior cultivars of* D. alata *and their attributes*

Cultivar	Recent source	Advantage	Disadvantage
'Alowinrin'	Nigeria	Uniform shape and color	Poor kitchen qualities.
'Belep'	West Africa	Good yield	Poor shape.
'Florido'	Puerto Rico	Compact shape, good flavor, high yields	Disease, nematode susceptibility.
'Forastero'	do	Vigor, good quality and yield	Susceptible to leaf spot.
'Gemelos'	do	Perfect shape, multiple tubers.	
'Murapoi'	Fiji	Good shape, thick bark	Polyphenolic oxidation.
'Nae Onwula'	Nigeria	Excellent shape and flavor	Poor yields.
'Pacala'	Ivory Coast	Good shape, color, and yield	Quality not as high as desired.
'Puka'	Ghana	Good shape and flavor	Low viability.
'Smooth Statia'	Caribbean	Excellent shape and flavor	Susceptible to virus.
'Suidie'	Ivory Coast	Excellent flavor	Poor keeping quality.
'Veeven'	Nigeria	Globular shape, good yield	Only normal cooking quality.
'White Lisbon'	Trinidad	Best cooking characteristics	Poor shape.
Unnamed	Nigeria	Heavy yields, good flavor	Irregular shape.

PN-4442

FIGURE 6.—Typical tuber of the select variety 'Florido'. (Two-fifths actual size.)

the flavor rich and free of bitterness, and the texture smooth. The tuber should be resistant to insects and fungi in the ground and in storage and should have a long storage life before germination begins. Germination in season should be dependable and rapid. A good yam can be processed into good fries, good chips, good flour, and good precooked, dried flakes.

It appears that *D. alata* varieties with good flavor and acceptable cooking characteristics are low in phenolic compounds, including anthocyanins. Although phenolic compounds (and polyphenolic oxidation) account for undesirable flavors and colors, these compounds may be also associated with disease resistance, since varieties with low phenolics seem more susceptible to diseases. External tuber characteristics appear to be unrelated to cooking quality.

Varieties selected by the author and their sources and characteristics are given in table 2. All are available for distribution.[3] Other superior varieties are expected to come out of the author's program. 'Florido' (fig. 6) is representative of a very good *D. alata* variety, but it is susceptible to leaf-spot disease. 'Gemelos' (fig. 7) usually gives excellent yields and has very high quality. The best variety for kitchen and processing quality, 'Forastero' (fig. 8), bears somewhat irregular tubers, but its superior cooking qualities compensate for this defect.

CULTURE

Environmental Requirements

The growth cycle of the wing-stemmed yam, a plant of shady rain forests, is intimately tied to a long rainy season followed by a short dry season. In perhaps all areas where this species has been successful, the dry period corresponds to the time of short days and lower-than-normal temperatures. When varieties are moved from one hemisphere to another, adjustment difficulties are marked, and 2 years may be required to change seasonal response. The factors controlling plant response are not known, but are suspected to include day length, temperature, and water availability.

When a collection of varieties is assembled and grown in one location, differences among their growth cycles become obvious. Some varieties mature consistently early, while others are consistently late. The tubers of early-maturing varieties may also germinate early. Thus, earliness is not necessarily related to shorter maturation time (which also varies from 7 to 10 months), but to a season of dormancy unique for each variety.

In addition to differing in season of dormancy, varieties also differ with respect to length of dormancy. Natural dormancy is closely related to storability. Varieties with tubers that store poorly are precisely those with short periods of dormancy.

Changing germination season, time to maturation, and maturation season is extremely difficult. Planting earlier than normal, for example, does not necessarily stimulate earlier germination by the same amount. On the other hand, tubers germinate at the appropriate season for the variety even when conditions for growth are unsuitable. This seasonal response of *D. alata* is one of its greatest limitations as a crop plant.

The wing-stemmed yam is

[3] Free tuber pieces distributed during January and February upon request to Mayagüez Institute of Tropical Agriculture, Agricultural Research Service, U.S. Department of Agriculture, Mayagüez, P.R. 00708.

PN-4443

FIGURE 7.—Tubers of the variety 'Gemelos', somewhat more branched than normal. (Two-fifths actual size.)

adapted to growth in the forest. In nature the relatively leafless new vine climbs rapidly through undergrowth to the tops of trees, where it spreads its foliage. The climbing habit makes it necessary to stake the vines for maximum growth and high tuber production. When vines are not staked, acceptable, but not maximum, yields are sometimes obtained.

Long rainy seasons are a requisite for optimal growth. Experiments have demonstrated that yields are reduced by drought. However, excessive rainfall can contribute to the spread of foliar diseases in susceptible varieties. Furthermore, the plants cannot tolerate excessive moisture around the roots and tubers.

If drainage is provided, *D. alata* tolerates a wide range of soil types and pH conditions. Deep, loose,

PN-4444

FIGURE 8.—Typical tuber of the variety 'Forastero'. (Two-fifths actual size.)

permeable clay soils are preferred. Sandy soils are not tolerated because they seldom retain enough moisture and frequently are not fertile. Drainage is best when the soil itself is permeable, but ridges and mounds are also useful in protecting plants from flooding. A high level of organic material in the soil is conducive to good drainage and aeration as well as to good nutrition.

Land Preparation and Planting

Because varieties of *D. alata* are grown in such widespread areas and by peoples with differing customs and skills, many techniques are used in their culture. However, the requirements of the varieties are the same. In this discussion the most advanced techniques are emphasized, although it is recognized that most yams are now grown, and may continue to be grown, by simpler techniques.

In Puerto Rico excellent yields of yams can be obtained in deep, well-drained clay soils without plowing or forking. In most soils the practice is to build ridges or mounds of soil by hand or machine. Since yams benefit from the addition of organic material to the soil, such materials can be spread over the soil first and then mixed in and formed into the ridge with a disk plow. This method was developed from primitive hand-mounding, still used throughout most of the Tropics. A second method is to place the organic material in trenches and to build the ridges over the trenches.

A particularly effective method for growing large yams is to accumulate organic materials in a hole or trench and to plant the seed yam directly in the hole. When very wide spaces are used in conjunction with tall vine supports and large seed pieces, very large, even giant, tubers are produced. Such practices are followed in New Guinea, other islands of the Pacific, and Trinidad to produce large tubers for competition or for ceremonial or display purposes.

New yams are always planted from existing tubers, pieces of tuber, or aerial tubers. Although most varieties of *D. alata* can be propagated from a one-node stem cutting (fig. 3), the technique is slow, and the resulting plants need at least a second year to mature. To stimulate root and tuber production of small cuttings, young stems are cut into pieces with one node and part of the stem on either side. The stem and node are buried in sand or other porous rooting medium and treated intermittently with mist spray for 1 or 2 months until rooted. Normally, the first tissue produced at the axil of the leaf is undifferentiated but becomes the primary nodal complex from which roots, tubers, and shoots arise.

When aerial tubers are available, they can be used as seed pieces. They usually germinate uniformly and produce vigorous plants. However, aerial tubers are usually small, and many are too small to produce plants of sufficient size in one growing season. In replicated trials aerial tubers have produced more tuber yield than comparably sized pieces of large underground tubers.

Small, whole, underground tubers of *D. alata* are sometimes used for seed. Although this practice might appear similar to planting an aerial tuber, small underground tubers often give poor results because their smallness may be the result of abnormal growth. Studies in Puerto Rico have shown that a large proportion of small tubers come from virus-infected plants, and plants grown from them are usually infected with virus.

The vast majority of yams are planted from pieces of mature tubers. Yams for seed should be selected from the largest and healthiest and stored at moderate to cool temperatures and moderate to low humidity. Seed pieces cut from tubers should weigh 100 to 500 grams. Planting is usually timed to coincide with the beginning of the rainy season. When sprouting begins in a few tubers, tubers should be sectioned and planted a few days later. When cutting tubers for seed pieces, rotten portions should be discarded. Cutting tubers weeks in advance or permitting sprouting before cutting are common practices but are not recommended. The cut surfaces should be dusted with wood ashes or a dry fungicide mixture and allowed to dry a little before planting. This procedure prevents rot in the soil, preserving the nutrients stored in the tuber piece for the growing plant.

Seed pieces are usually made by cutting the yam crosswise. The piece including the plant crown has preformed buds and germinates readily. The tender growing tip of the tuber often does not germinate very well. (However, there is disagreement on this point.) The midsections usually germinate well after new buds have developed. To avoid the problems of middle and tip sections, the crown ends of tubers to be used for food can be cut off and saved for seed. These pieces, which are tougher and more fibrous than the remainder of the tuber, are likely to have low value as food anyway. Clarification of the relative ease of germination of the various sections as related to tuber age and cutting time is desirable.

The germination of seed pieces can be stimulated to some extent. High temperatures (40°–60° C) for 1 hour or more advance germination 1 or 2 weeks. Planting stimulates germination, probably by furnishing warm and humid conditions. Cool, dry storage increases the dormant period. There are limits to these techniques, but they have not been investigated systematically. The biological clock mechanism of the variety is probably the most important factor determining time of germination.

Chemical treatments have been useful in stimulating germination. An 8 percent solution of ethylene chlorohydrin (2-chloroethanol) used as a dip 4 to 6 weeks after harvest is said to cause germination of most tuber pieces in 2 to 3 weeks (*6*). The concentration necessary to stimulate germination decreases as the season of dormancy passes. An ethylene-releasing substance, ethephon, is also useful in stimulating germination. It is effective in concentrations as low as 0.4 percent in water when applied in a 5-minute dip.

Seed pieces should be handled with great care. They are planted by opening a hole in the soil with a small hand hoe and placing the tuber piece in it. Some persons feel that the orientation of the tuber piece in the hole is very important and that the cut surface should face upward. The seed is covered with about 10 centimeters of soil to prevent its drying. Occasionally, a mulch of dried plant material is placed over the planting site. In West Africa mulching retains soil moisture in the root zone and significantly increases yields. Planting can be simplified by opening a furrow with machinery, dropping in the seed pieces, and then covering the furrow.

Optimum planting distances depend on many factors, and local trials should always be made. For culture of giant tubers, spacing of 2 or 3 meters is justifiable. One meter between plants is usually adequate. When yams are planted in machine-made rows, the rows should be 2 meters apart and the plants, 0.5 meter in the row.

Fertilization

Considerable controversy exists with respect to the fertilization of *D. alata*. Common observations have shown that organic material in large amounts is useful, but that it should be partially rotted before use. Organic materials are added before or at the time of planting.

Mineral fertilizers have given equivocal results and at times have actually reduced yields. Nevertheless, a pattern of needs has emerged from many experiments. During the first 6 weeks of growth, plants rely heavily on the nutrients stored in the seed piece. Then, during the first half of the growth period, they need large quantities of nitrogen to sustain vegetative growth. When tuberization occurs, much potassium is required.

Among the fertilizer recommendations given are the following: Nigeria, 12:12:18, 60 grams per plant (*9*); Trinidad, nitrogen, 100 kilograms per hectare applied 3 months after planting (*16*); Dominica, 3:9:18, 30 grams per plant 4 to 6 weeks after planting (unpublished); Barbados, ammonium sulfate and muriate of potash, about 200 kilograms of each per hectare (*13*). With such a wide variety of recommendations exact advice cannot be given; mineral fertilization trials will always be necessary for particular locations and cultural practices. When inexpensive organic material is available, it will probably always be advantageous to use it, especially at heavy rates (5 to 50 metric tons per hectare).

Staking

As a rule, stakes for climbing guarantee better yields. However, the gain in yield must be balanced against the cost of the staking system. In most locations it is profitable to stake, and some inexpensive staking method should be sought. When necessary, however, the wing-stemmed yam can be made to produce without staking.

Staking plants with banana, corn, pigeon peas, and other crop plants has not proved beneficial. The support plants compete for nutrients with the yam crop and usually reduce yield considerably.

The staking system used should rely on local materials. The stakes should be about 2 meters tall. Taller stakes drastically increase installation costs, are difficult to manage, and may not increase yield sufficiently to justify their cost. Individual stakes are preferred over systems of strings or wires, which encourage the vines to become tangled.

One of the best staking systems was developed in Trinidad (*30*). Twelve-foot teak poles are placed in holes every 30 to 50 feet in a row and supported by guy wires. The poles are strung with 12-gage galvanized wire 6 to 8 feet off the ground. Two rows of yams are planted, one on each side. When the vines are sufficiently developed they are tied with strings, which are passed over the wire. Sufficient space is left between rows of poles to provide access to the vines. In a variation of the technique a lower wire is also used, and strings are passed between the two wires. Details of this well thought-out technique merit study.

It is not unusual to find the wing-stemmed yam growing without support (fig. 9). On Barbados, it is normally grown between crops of sugarcane. Before the cane is planted, yams are planted on the ridges and usually given some fertilizer. They soon cover the ground. Under this condition weeds are somewhat difficult to control, and the vines do not reach their maximum development. With careful attention to details, stakeless culture can yield up to about 10 metric tons per hectare, about one-third of the yield of staked yams under optimum conditions.

Pests and Diseases

Dioscorea alata foliage is usually free from serious insect pests. Susceptibility is closely related to variety. The work of leaf-cutting insects (fig. 10) detracts from the appearance of vines but does little damage. Mites, mealybugs, scale insects, and caterpillars are sometimes seen. The best review of insect pests is Coursey's (*9*).

On the other hand, various species of beetles can severely damage the tubers in the ground or after harvest. The worst of these, *Heteroligus meles* (Billb.), the

PN-4445

FIGURE 9.—*D. alata* growing without stakes.

greater yam beetle, passes through its mating and reproduction cycle in swamp ground but migrates to yam plantings for feeding. In Puerto Rico white grubs, *Lachnosterma* spp. and *Diaprepes abreviatus,* often cause extensive damage to the tubers. These beetles have been controlled by the application of insecticides to the soil, a risky practice. In most parts of the world yams are not treated in any way to protect them from insect pests.

A serious plague limiting yams in some areas is the nematode. Although these small organisms have been chiefly associated with African species, they can also be very detrimental to *D. alata*. The species attacking yams are *Scutellonema bradys* (Steiner and Le Hew) Andrassy, *Meloidogyne* spp., and *Pratylenchus* spp. Damage occurs chiefly to the tubers, in the form of superficial lesions that permit the entrance of fungi. Where yams are grown in sandy soils, nematodes constitute a serious problem and control is difficult. Practical control includes the use of clean seed materials and planting in heavy soils, where nematodes might not occur. In some cases hot-water treatment kills the nematodes in the tissue. Extended cool treatment in a refrigerator is also useful. Nematodes are often present in harvested yams and may continue to live and multiply in stored tubers (*29*). They are suspected to be associated

PN-4446

FIGURE 10.—Insect damage and angular leaf spots on leaves of a particularly sensitive *D. alata* variety. (Two-fifths actual size.)

with dry-rot disease, which affects tubers in the ground or in storage.

The pests attacking yam merit more study because they constitute perhaps the chief risk to the expansion of yam production in new areas, and in most areas, rotting and loss of quality are inevitable results of infestation. Since the biology of some of the species is complex, no easy solutions can be expected.

The most serious foliage disease of the wing-stemmed yam is leaf spot (fig. 11). The disease appears as very small brown or blackish spots on the leaves and stem. The spots enlarge, the uninfected leaf tissue tends to yellow, and eventually the leaves die, but may hang on the vine for long periods. Premature dieback of leaves and stems drastically reduces yield. The disease is generally attributed to a species of *Colletotrichum,* but other fungi might be involved, perhaps in secondary roles.

Although leaf spot can be found on the leaves of almost all *D. alata* varieties at all times, severe infections generally occur late in the growing season, when the yams are switching from the production of vegetation to the production of tubers. At this stage, aided by rains, the disease can spread rapidly, affecting much of the foliage. The vines wilt in severe cases.

The most effective control of leaf spot is the use of resistant varieties. Many have been found, but most of these do not have desirable agronomic characters. Selection of varieties from a broader base of germ plasm appears promising, however. When acceptable resistant varieties are not available, the disease can be controlled by the use of copper-based fungicide. In addition, zineb and ferbam sprays at 10-day intervals have been reported to be useful. If rains are frequent, control is seldom effective, and repeated ap-

PN-4447

FIGURE 11.—Leaf-spot disease of *D. alata leaves.* (Two-fifths actual size.)

PN-4448

FIGURE 12.—Mosaic disease of *D. alata* leaves.

plications become expensive. Therefore, good varieties of *D. alata* susceptible to leaf spot are often grown only in areas fairly free of the disease or where weather conditions are not conducive to its full development.

In addition to leaf spot, mosaic (fig. 12) diseases of the leaves often cause severe losses in plantings of the wing-stemmed yam. Leaf symptoms include dwarfing, narrowing, crinkling, and other distortions of shape; mottling; and vein banding. Such symptoms vary not only among plants of a single clone but also among the branches and the leaves of a single plant. In most cases the symptoms have been attributed to virus, but the range in type and intensity of the symptoms suggests that more than one virus is involved. In a few cases the presence of a virus has been verified.

The virus diseases of *D. alata* have not been well studied, but certain generalizations based on experience can be made. Once a virus disease occurs in a planting, it tends to extend itself rapidly, and new plantings tend to be more diseased than previous plantings. The tubers of heavily infected plants are smaller than those of lightly or apparently uninfected plants. When planted, they produce heavily infected plants. Tubers from symptomless plants may be symptomless but nevertheless virus infected. Occasionally, symptomless plants grow from the tubers of lightly infected plants, and thus selection of seed stock with low virus symptomolgy is possible.

Regular rogueing appears to be the best protection against mosaic disease. Treatment of infected tubers by hot air over long periods has also rid them of disease. In yams grown for medicinal purposes, similar symptoms have been shown to be carried by aphids. Control of insect pests appears to be an effective way of reducing spread of the disease.

Rotting of tubers in storage is common and accounts for most losses after harvest. Rotting is often associated with wounds inflicted at harvest and can be reduced by careful harvest. A curing period of about 1 week in warm, dry conditions leads to the formation of a cap of dry cells that protect wounds against fungal entrance. Afterwards, a cool temperature and moderate humidity are required for maximum storage life. Rotting is also associated with insect and nematode lesions and with a history of poor drainage around the tubers.

Many organisms are associated with storage rots. Soft rot is caused principally by *Botryodiplodia theobromea*. Indoleacetic acid solutions applied to the yam tubers before storage are useful in suppressing the disease. Nematodes are associated with dry rot before and after storage. The most important organisms in the rotted tissue are *Rhizoctonia solani* and *Fusarium oxysporum*. From other rots the organisms *Penicillium oxalicum* and *Aspergillus niger* have been isolated. A common treatment to avoid rot is to dust the tuber, especially its cut surfaces, with wood ashes or other alkaline substances. Avoiding damage at harvest is the best preventative measure.

A brown spot found within the living tuber of *D. alata* affects food and keeping quality (*10*). The brown nodules are concentrated near the crown end of the tuber. Plants grown from tubers with this condition show virus symptoms of the foliage, and bundles of filamentous particles can be seen in the tissues with the electron microscope. The virus appears to be of the class found in cacao swollen shoot and may thus be transmitted by mealybugs as well as other insect vectors.

Because the virus diseases of yams are not well understood, introduction of varieties from one region to another is hazardous, even though it appears that virus is universal in its culture. Unless needed for study purposes, virus-infected plants should be rooted out of plantings as soon as detected. Large tubers from healthy mother plants should be selected as seed material. In this fashion it should be possible to reduce virus occurrence in commercial fields to a tolerable level.

Harvesting

Near the end of the growing season, which generally coincides with the beginning of the dry season and shorter days and cooler temperatures, vegetative growth ceases in most varieties of wing-stemmed yams. Flowers and aerial tubers are sometimes produced. At this time the underground tubers are also produced. These develop rapidly until the foliage dies back. It is not known what triggers seasonal dieback, but once begun, fungi often kill the foliage rapidly. This terminal fungal infection of the leaves, not invariable, should not be confused with premature dieback associated with *Colletotrichum*. Tuber growth cannot continue after the foliage has dried up, but maturation of the tissue may continue, and in particular the cork cap over the tuber will continue to develop. Therefore, it may be advantageous to harvest several weeks after foliage dieback.

Tubers are frequently dug with special sticks that look somewhat like large spoons. Conventional spading forks and shovels are more useful.

Most varieties of *D. alata* produce large, deep tubers that must be dug with some care. On the other hand, a few varieties produce compact, often multiple tubers near the surface of the soil. Conventional machinery for the harvest of potatoes and sweetpotatoes can be adapted to such varieties. In these cases it may be necessary to remove vines and staking systems first. Needless to say, mechanical harvesting is facilitated by planning spacing in advance and by using ridges of soil from which tubers can easily be removed.

Poor care, bad weather, and disease can reduce yields to zero. On the other hand, favorable combinations of variety, cultural technique, and weather can produce exceptional yields. Unfortunately, high rather than average yield figures tend to be made available, so it is difficult to know what typical yields are.

Exceptional weights of individual tubers have been recorded. Haynes and Coursey (*16*), in a study of giant yam production in Trinidad, mention tubers up to 81 kilograms. This weight compares favorably to that of the largest yams produced in Papua New Guinea. These giant yams are produced by giving them individual attention not compatible with commercial production.

An experiment station's yield from small plots sometimes reaches 40 to 50 metric tons per hectare. Normal yields under very good agronomic conditions range from 15 to 20 metric tons. In Barbados yields obtained without stakes range up to about 18 metric tons per hectare under the very best conditions (*13*). In Fiji yields range from 4 to 25 metric tons per hectare, depending on staking and size of seed piece (*2*). Coursey (*9*) has summarized typical yields as follows: Southeast Asia, 12 to 25 metric tons; West Indies, 20 to 30 metric tons. These estimates appear too high.

In summary, very excellent yields can be obtained when cultural conditions are appropriate, and exceptional varieties of yams can outyield most other farinaceous crops.

CULINARY CHARACTERISTICS

Many varieties of the wing-stemmed yam present problems in the kitchen. First, one tuber is usually too large for a single meal, so a part is used and a part saved. Since the cut surface is often dirtied or dries and cracks, using a tuber for several meals increases wastage. Second, many tubers are irregular in shape and are therefore hard to peel. Third, the bark is sometimes thick and corky and difficult to remove; this characteristic is an advantage, however, for it protects the tuber against wounds. Cleaning and preparing such yams for cooking can be an arduous chore best avoided by use of better varieties. Very few varieties of *D. alata* produce small tubers that can be boiled or baked without peeling. On the other hand, many good varieties yield tubers of regular shape that are convenient to use. These, however, are poorly distributed and not known in much of the yam-growing world.

When the tuber is cut open, sticky proteinaceous gums exude. The cut surface begins to change color with the oxidation of polyphenolic substances and may become gray or ugly brown. Protection of the surface from oxygen by cellophane or any impermeable membrane decreases oxidation tendency. Polyphenolic oxidation is associated with off-flavors, including bitterness, and should be avoided. There is some suggestion that spots that oxidize readily are associated with virus infection. The cut surface may sting human flesh, especially tender areas such as the inside of the wrist. This sting, associated with calcium oxalate crystals, usually disappears in about 10 minutes.

The flesh of the yam varies in texture. Coarse texture, which looks a little like soured milk, is caused by the association of vessels in thick bundles. In some varieties the texture is very fine, and such bundles cannot be seen.

The flesh also varies in color. Yellow, unusual but not unknown in *D. alata,* is sometimes due to the presence of still unidentified carotenoids. Yellow color is distributed evenly and is usually maintained during cooking. When associated with polyphenolic oxidation, however, the resulting brownish gray is very unappetizing. The purple color of anthocyanin is usually not distributed uniformally through the tissue, and except to the eyes of those who prefer such yams, the appearance is not appealing. The flesh of the best varieties is very white, smooth, free of the appearance of texture, and low in oxidizing tendency.

It is difficult to distinguish the taste of *D. alata* tubers from those of other edible species. Nevertheless, considerable variation exists, and some yams are recognized as tasting better than others. In areas where the fine-textured, white-fleshed varieties are not seen, coarse texture and strong flavor are very much appreciated. These coarse yams are not very good for processing. Among persons just learning about yams, the palate is rapidly accustomed to the fine, white types. It is a general belief that such types were selected and ennobled by early man. Good yams for eating have rich characteristic flavors that are well accepted by almost all persons. They may be slightly sweet, especially after long storage.

COOKING AND PROCESSING

By far the greatest use of the wing-stemmed yam is as a boiled vegetable. The tuber is served in pieces or mashed or in soups, where, finely divided, it serves as a thickener. Tubers are sometimes roasted, or the mashed yam is fried as a cake. In these forms yams are often eaten with an oil or a sauce.

A special potential for yam cookery is french fries and chips. The best varieties for these purposes have fine, dense flesh, low polyphenolic oxidation, and no anthocyanin. Frying at 190° C in corn oil or corn oil-lard mixtures results in products superior to similar potato products. Varieties especially suited for fried products have been selected (*23*).

The preparation of instant yam flakes has been investigated in Puerto Rico, Trinidad, and Barbados (*14*). The processes are washing, lye peeling, trimming, slicing, cooking, maceration or finer cutting, mixing with water, drum drying, and packaging. The flakes store well, are easily prepared for the table, and have good flavor. Quality is strongly influenced by variety, but rather coarse yams with a tendency to oxidize may yield very acceptable instant flakes if an antioxidant is used, beginning with the slicing operation. The costs of processing would probably make exportation, but not domestic consumption, profitable.

Flours have been made from yams by simple processes by many peoples. Flours made from dried yam must be distinguished from the use of fresh yam as a substitute for flour in baking. Whereas the former process permits storage of the yam, the latter may be considered as just another way to use fresh yam. The usual technique has been to peel and slice the tuber, dry the slices in the sun, and then grind the slices into meal. If moisture content is lowered sufficiently, dried powdered yam can be stored for a long time. Such flour can be cooked to yield a thick soup or mashed yam or can be substituted for all or part of other flours in baking. Flours prepared by such techniques are often gray to black, from mold growth and polyphenolic oxidation, and are not favored except when fresh yams are not available.

With modern techniques a higher grade of flour can be produced. In an ideal process the yams would be washed, lye-peeled, trimmed, cut into pieces, dried with hot air, ground into a fine flour, sieved to appropriate size, and then packaged. Laboratory experience shows that the flour potential of *D. alata* varieties differs. Pigments in the flesh or a tendency towards polyphenolic oxidation results in off-colored flours or unappetizing odors or flavors. The best yams for flour have fine, dense, perfectly white flesh, the same varieties preferred for boiling and frying.

In contrast to flours of other farinaceous roots and tubers, yam flours can be substituted for wheat flours at a higher percentage, perhaps as much as 60 percent. The success of this substitution possibly is related to the high protein content of the tubers or perhaps to its mucilagenous character. However, as the percentage of yam flour increases, certain problems are encountered, among them, poor crumb quality and poor rising of the dough. Taste panels have judged products made from yam flour, including pancakes, cupcakes, conventional bread, and hard bread rolls, acceptable to delicious.

The nutritional value of yam-wheat flour mixtures needs study. Since the protein content of the two simple flours is about the same, the total protein may not change by combining them. Nevertheless, the relatively high lysine content of yam flour and the complementary content of methionine in wheat flour should result in a mixture of high nutritional value.

The realistic use of yam flour calls for a cookery based only on it, not on a mixture of flours. Such a cookery needs to be developed not only for homemade flour but also for commercially produced and marketed flours. The potential of yam flour in the processed-food industry merits investigation. If yam flour is to become widely used, techniques to produce yams more cheaply, probably through mechanization, need to be developed.

COMPOSITION

The dry weight of the edible portion of the yam is about 15 to 35 percent of the fresh weight. High dry weights are associated with fine structure, dense feel, and high quality. Maximum dry weights are achieved near the end of the dry season. High density is a varietal character that is not changed much by environmental influences.

The composition of five varieties of *D. alata* was reviewed by Wildeman (table 3). Water is the chief ingredient, of course, followed by starch. The lowest starch figure, 15 percent, represents the content of an immature tuber, and few varieties would assay less. As a

TABLE 3.—*Tuber composition of five* D. alata *varieties*[1]
[Percent of whole-tuber weight]

Substance	Variety				
	1	2	3	4	5
Water	77.60	65.95	67.12	72.42	76.15
Starch	15.60	19.50	23.87	17.71	19.34
Mucilage or protein	2.10	5.68	1.36	6.87	1.31
Cellulose	1.10	7.50	3.15	2.53	.65
Sugar	(2)	1.19	.50	1.00	(2)
Minerals	.96	(2)	(2)	(2)	.73
Fats	.23	.18	.11	.04	.16
Not determined	2.41	....	3.89	.43	1.66

[1] From Wildeman (*31*).
[2] Not given.

group the varieties contain less starch than usually reported; it is not uncommon to find tubers with 28 percent starch. Little carbohydrate occurs as sugars. The amount of cellulose is low; in fact, very few tubers contain enough cellulose to present a fibrous appearance. Fats are negligible. Vitamin C in useful quantities has been reported. Minerals are not important components.

Starches, which make up 13 to 32 percent of the tuber, are relatively difficult to extract from *D. alata*. During peeling and cutting, the equipment is likely to become clogged with released water-soluble gums, which must be dispersed with large amounts of water. Once the gums are dispersed the larger particles of starch settle to the bottom of the container in about 24 hours. The starch must then be resuspended in water two or three times and allowed to settle. The resulting starch cake can then be dried. Starch prepared in this fashion contains few other materials, but can be expected to have 13 to 18 percent moisture and 1 to 4 percent protein.

The particles of *D. alata* starches are mostly large and pyramidal in shape. One point of the pyramid represents the small grain on the side of which successive layers of starch are deposited. The mature grains vary from 1 to 7 micrometers in diameter, although much larger grains have been reported, making the grain considerably larger than that of cassava, a major source of industrial starch. The large size might make *D. alata* starch difficult to digest, especially when uncooked.

The amylose content of *D. alata* starches ranges from 19 to 20 percent, somewhat higher than that of *D. esculenta*, but not significantly different from that of cassava. The viscosity of *D. alata* starches has been reported to be moderate, although there is much variation among varieties. Probably none approximates the viscosity of the starches of the African species *D. rotundata.* The starch gel is opaque.

The properties of *D. alata* starches need more study in reference to industrial use. Sufficient differences have been found among varieties to suggest that selection for particular starch types might be possible. Yam starches would probably be useful in a number of industrial processes, but their cost is high compared to the cost of corn and cassava starches.

D. alata tubers contain surprisingly large amounts of protein (*24*). About 85 to 95 percent of the nitrogen can be recovered as amino acids. Varieties that contain only 6 percent protein, a low figure for yams, thus contain three to four times more protein than their rival staple, cassava. Moreover, many varieties contain 8 percent protein and as much as 15 percent has been recorded.

The protein of *D. alata* is not well balanced (table 4). However, usually only the sulfur-bearing amino acids methionine and cystine are particularly short. The percentage of these desirable amino acids has not been carefully estimated but varies from 20 to 50. It should be possible to select varieties with fairly balanced protein, for strong varietal differences exist, not only in protein content but also in sulfur-bearing amino acid content (table 5). In the absence of selected varieties, proteins high in methionine should supplement staple yam diets. Lysine is often present in greater-than-normal quantities in *D. alata* tubers.

The red and purple pigments of *D. alata* are anthocyanins of cyanidin. Purple forms occur in the parenchyma of the tuber tissue,

TABLE 4.—*Essential amino acid content of* D. alata *cultivars compared with FAO reference protein*

[Grams amino acid per 100 grams protein]

Amino acid	FAO reference protein[1]	Cultivar				
		'Florido'	'White Lisbon'	'Forastero'	'Barbados'	'Smooth Statia'
Valine	4.2	4.9	4.8	5.2	4.7	4.8
Isoleucine	4.2	4.2	4.2	4.7	4.0	4.1
Leucine	4.8	7.7	7.8	7.4	8.1	8.1
Threonine	2.8	4.2	3.9	7.1	3.9	4.2
Methionine	2.2	1.6	1.5	1.6	1.5	1.7
Cystine	2.0	.4	.4	.2	.4	.3
Phenylalanine	2.8	5.8	5.8	5.9	6.1	6.1
Tyrosine	2.8	2.8	2.7	2.2	3.1	3.0
Lysine	4.2	5.1	5.0	4.8	5.0	5.4

[1] FAO Nutritional Studies 24 (*12*).

TABLE 5.—*Protein, total amino acids, and sulfur-bearing amino acids in* D. alata *cultivars*

Cultivar	Total protein[1] (g/100 g)	Total amino acids[2] (g/100 g)	Sulfur-bearing amino acids[3]				
			Total	Methionine		Cystine	
			(g/100 g)	g/100 g	Percent	g/100 g	Percent
'Ashmore'	7.21	5.60	0.10	0.09	1.57	0.01	0.16
'Barbados'	8.12	6.36	.12	.09	1.47	.03	.41
'Bottleneck Lisbon'	7.25	5.65	.11	.09	1.54	.02	.40
'Brazo Fuerte'	6.28	4.69	.23	.16	1.57	.07	.68
'Corazón'	9.16	6.03	.12	.09	1.55	.03	.43
'Cuello Largo'	11.22	8.13	.19	.14	1.70	.05	.57
'De Palo'	8.88	7.34	.14	.12	1.63	.02	.27
'Espada'	10.82	7.11	.12	.11	1.59	.01	.17
'Farm Lisbon'	8.25	6.43	.12	.10	1.51	.02	.36
'Feo'	8.16	6.68	.16	.12	1.86	.04	.54
'Florido'	10.47	8.22	.17	.13	1.58	.04	.43
'Forastero'	7.25	5.64	.10	.09	1.60	.01	.17
'Gordito'	8.47	6.61	.13	.11	1.67	.02	.29
'Hawaii Branching'	8.28	6.07	.11	.09	1.56	.02	.28
'Hunte'	9.22	6.96	.12	.11	1.62	.01	.21
'Macoris'	7.68	6.08	.12	.09	1.54	.03	.15
'Morado'	8.04	5.99	.11	.09	1.48	.02	.28
'Oriental'	7.72	6.32	.13	.11	1.72	.02	.27
'Prolific'	9.44	7.38	.14	.11	1.50	.03	.35
'Purple Lisbon'	7.66	6.16	.10	.09	1.50	.02	.36
'Pyramid'	9.41	6.03	.13	.10	1.61	.03	.48
'Seal Top'	7.84	5.73	.12	.09	1.57	.03	.58
'Smooth Statia'	6.56	5.23	.11	.09	1.67	.02	.29
'Sweet'	6.84	4.81	.12	.09	1.90	.03	.53
'Vino Blanco'	8.06	6.50	.11	.09	1.45	.02	.34
'Yellow Lisbon'	7.91	5.99	.13	.10	1.60	.03	.42

[1] Percent of whole-tuber weight, dry basis. [2] Grams per 100 grams protein, dry weight. [3] Grams per 100 grams protein (dry weight) or percent of total amino acids, as indicated.

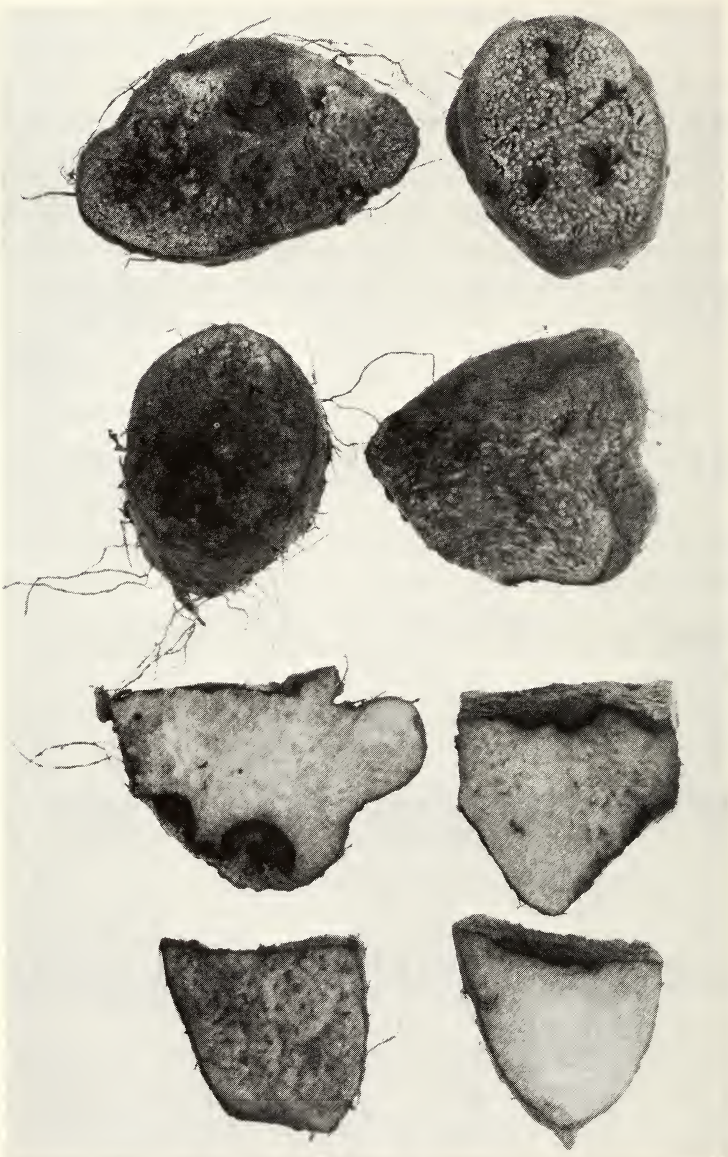

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FIGURE 13.—The cut tubers on the left were cured in hot, dry air. The tubers on the right were uncured and are beginning to rot. (One-half actual size.)

whereas red forms occur chiefly in the foliage and in the cortex of the tuber. The occurrence of anthocyanins is somewhat related to taxonomic grouping of the varieties. More advanced and highly selected varieties contain little or no anthocyanin. When foliage is free of anthocyanins, so are the tubers. Varieties with high anthocyanin content are often prone to polyphenolic oxidation, and their tubers are usually much branched and agronomically inferior.

Although the yellow pigments of *D. alata* have not been well studied, there is no reason to believe they are different from those in other species of yams, which contain principally xanthophylls and their esters, although the vitamin A content is sometimes high enough to be of nutritional significance. Good yellow-fleshed varieties of *D. alata* would be desirable for vitamin content.

STORAGE

Some say wing-stemmed yams store well; others say they have poor storage characteristics. These conflicting points of view probably reflect experiences with different varieties or with different storage methods. It is well recognized that injured tubers can be readily infected with fungi and that fungus diseases can destroy entire tubers, often in a short time. Furthermore, once started in a tuber, fungi are almost impossible to eradicate. Therefore, tubers that are damaged at harvest should be used as soon as possible and should not be stored.

The first week after the harvest is crucial to the storage life of tubers. Curing under humid conditions invariably results in rapid fungal growth. Curing by hot, dry air permits the development of a layer of dead cells that protects against fungal infection (fig. 13). Cut surfaces do not develop a new meristematic layer, and a wound periderm is not formed. The dry cells are not suberized. If the dry-air treatment is too long, excessive moisture loss leads to cracking, permitting severe fungal infection. After curing, moderate humidities and cool temperatures (15°–17°C) can give a storage life of a year or more.

Storage practices vary. Storage in the ground (delayed harvest) is common, but insect damage increases, the risk of loss from rats, pigs, and humans must be confronted, and early rains may impede later harvest or lead to premature sprouting. Nevertheless, the quality of tubers stored in the ground is as good as that of tubers harvested and stored elsewhere.

Tubers are often stored by piling them in pits, tying them to walls, or placing them on shelves in yam barns. They can keep well under these conditions. Free circulation of air around the tubers helps avoid rot. Under these conditions tubers begin to germinate when their normal season of regrowth occurs. Sprouting rapidly diminishes the starch reserves of the tuber and reduces flavor.

The storage of yams in piles is common but should be discouraged. In piles, rotting can spread rapidly, and since it is hidden, it cannot be controlled. Leaving the tubers in the sun for extended periods severely reduces storage life.

Storage life can be increased by chemicals. The most effective is MENA, the methyl ester of alpha-naphthaleneacetic acid (*7*). Tubers are packed in papers treated with the chemical at the rate of 100 milliliters reagent in 100 milliliters acetone applied to 250 grams of packing paper. Although rate of water loss is not affected to any great extent, tubers remain in edible conditions from 1½ to 2 months longer than normal. The tubers develop a warty surface after 6 months. Results are about the same if the tubers are treated at harvesttime or 2 or 3 months thereafter. The cost of the treatment, however, may limit its use.

In addition, preliminary small-scale experiments have shown that dipping tubers in weak solutions of gibberellic acid can delay germination 2 to 3 months. Experiments are needed with this hormone, which acts powerfully even at low concentration, to see if some type of treatment similar to that with MENA can be devised, in which the active chemical is constantly available to the tuber.

Storage of wing-stemmed yams at 10° to 12° C or less results in a characteristic low-temperature injury (*11*). When tubers are returned to normal temperatures, death of tissue, internal breakdown, foul odor, and decomposition follow rapidly. The cause of the disorder has not been determined.

A problem in marketing, in industry, in the kitchen, and in the design of scientific experiments is the great variability of *D. alata* tubers, not only among varieties of the species but also within the same variety. Undoubtedly, this variation has led different investigators to different conclusions. The problem of variation is associated with many factors, such as source and size of the seed piece and virus disease in the tuber. In a few cases clonal selection has reduced variation, probably by elimination of heavily diseased tubers. The best assurance of high uniformity, however, is growing plants under optimum conditions in loose soil, where they can reach their full potential in size and shape.

POTENTIAL USES

The wing-stemmed yam has a bright future throughout the Tropics wherever subsistence agriculture is practiced and rainfall is sufficient. Because of the excellent flavors of yams, they will probably always be more popular than other roots and tubers. Nevertheless, because they need special attention, especially staking, they may not complete well with cassava, sweetpotatoes, and aroids. The wing-stemmed yams may thus play a progressively narrower role in subsistence agrictulture. On the other hand, the size of the role may increase. Better varieties, now being selected from a worldwide collection, will be distributed throughout the Tropics and will replace many inferior types now in use. In some areas, these may increase the popularity of yams.

A successful future for *D. alata* depends on extending the yam season or avoiding waste of the too abundant, too short harvest. The possibility of planting and harvesting all year around does not appear good because seasonal response is difficult to change and a broad enough spectrum of varieties is not available for staggered year-long planting. Year-round production in some locations near the Equator with well-distributed rainfall might be possible, but in most cases, yams will mature during the dry season and will be overabundant.

Improved storage of tubers is probably the best solution for extending availability of *D. alata* in subsistence agriculture. Simple techniques of storage in pits and yam barns are already known, but information about their relative merits is not readily available. It is hardly likely that research will improve techniques for the small farmer, but the economies of common storage techniques do need to be compared and evaluated.

Extension of yam availability can also come about through wider use of processed products. Of these, the most important is flour, but neither the present processing techniques nor the varieties of *D. alata* now available can be recommended. With respect to the varieties, the chief problems are irregular tuber shape, a difficulty in preparation; excessive polyphenolic oxidation; and drying. The first two problems can be resolved, perhaps, through the use of better varieties. The problem of drying can be attacked through the use of inexpensive solar dryers. To complement the dryer, inexpensive household devices are needed to peel and chip the tuber. These devices will have to cope with the large quantities of gums released in the operation.

Finally, new cooking techniques and recipes are needed for new and stored yams and for yam flour. In particular, bread recipes using yam flour in place of imported or purchased flour should be developed.

Overall, then, the future of the wing-stemmed yam in subsistence agriculture appears good. The distribution of varieties and knowledge, the development of new techniques for preparing flour, and new recipes will help assure that future. However, the greatest future for *D. alata* should lie not in subsistence but in modern agriculture, since progress for large numbers of people requires that more food be produced more economically. This has heretofore been accomplished by the use of machinery powered by fossil fuel.

The energy relationships of mechanized agriculture and the long-term consequences need to be restudied. Nevertheless, it is tempting to believe that long-term energy problems will be solved, allowing the continuance and extension of mechanization.

As previously mentioned, most operations in the production of yams can be mechanized. In order to benefit from mechanization, the scale of farming must be increased. When yams are grown on a large enough scale, two problems not now meriting attention can be studied: the production of seed yams in special nurseries and the mechanization of staking systems. Or, as an alternative, it may be feasible to grow unstaked yams economically when all operations are mechanized.

In considering the future of the wing-stemmed yam, its competitors must be taken into account. The African yams, with their more stringent growth requirements and adaptation to certain climates, will probably not compete successfully with *D. alata* except in West Africa and a few other locations. On the other hand, new varieties of *D. esculenta* recently collected show great promise and may replace *D. alata* in some places.

The real competition for the wing-stemmed yam comes not from other yam species but from other roots and tubers. Chief of these is cassava, *Manihot esculenta* Cranz, which has already displaced yams in many parts of the Tropics. There is no evidence that the march of this crop will be detained, but its victory will be unfortunate, because the food value of cassava does not reach that of the yam. In other areas aroids and sweetpotatoes do and will continue to compete with the yams. To compete better, select varieties of the wing-stemmed yam are needed, and based on these varieties, modern agronomical techniques must be developed.

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