Journal of Root Crops, 2015, Vol. 41 No. 2, pp. 3-16
Indian Society for Root Crops
ISSN 0378-2409, ISSN 2454-9053 (online)

Taxonomy and Conservation of the Genus *Dioscorea* in Western Ghats

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Received: 3 January 2014; Accepted: 20 July 2015

Abstract

The genus *Dioscorea* L. is one of the largest groups among monocotyledons belonging to the family Dioscoreaceae in the natural order Dioscoreals (Ayensu, 1972). The genus has about 850 species in the world and distributed mainly in three centres of diversity namely South Africa, South East Asia and Latin America (Mabberley, 2005). The members are commonly known as "yams" and are widely cultivated for its edible tubers throughout the tropics and occupy third position as the most important food crop in the world next to cereals and pulses. They are mainly represented by herbaceous twinning climbers which lack tendrils. They usually inhabit forest margins, open habitats and are distributed upto 3500 m above mean sea level (MSL). The aerial stem twines on the neighboring vegetation and the twining features are often species specific. The leaves are with variable phyllotaxy and distinctly petiolate. Bulbils are also present in many of the species. The underground stem is called tubers and it is the most important part of the plant. The plants are usually dioecious and the inflorescences are axillary spikes with actinomorphic flowers. The genus *Dioscorea* exhibits a number of morphological, anatomical and embryological characters which are reminiscent of dicotyledons (Bouman, 1995). Most of the yams are edible and also certain species possess medicinal properties. The global production is estimated about 56,000 million tonnes (FAO, 2012). It is a staple food in various parts of the world especially in many tropics and subtropical regions (Cooke et. al., 1988). Yams have potential for increased commercial exploitation in the area of food processing and pharmaceutical industries (O'Hair, 1988). Nutritionally, like other root or tuber crops, yams are essentially rich in starch or carbohydrate, which provide extra calories and thus get a comparable position to that of potatoes. They play an important role not only in the nutrition but also an integrated role in the cultural life of the people.

In India, there are 32 species of *Dioscorea* reported of which, 21 are distributed in Western Ghats and about 5 million people are directly or indirectly depend on this crop for their food, feed, and medicine. In spite of its manifold economic importance, the group is not taxonomically well studied for the last 60 years except a few attempts by flora workers. This is mainly because of its dioecious nature, variable phyllotaxy, different phenology of the same species, deep seated underground tubers which makes the group much more difficult for researcher and hence neglected. Against this backdrop, the present study was undertaken to delimit and unravel the species complexity that exists in the Western Ghats based on fresh explorations from the wild as well as in cultivation for conservation and sustainable utilization.

Key words: Western Ghats, dioscorea, taxonomy, conservation, utilization

Introduction

The family Dioscoreaceae was first described by Robert Brown in 1810. The family is a wide spread and variable one which extends not only throughout the tropical world but also in temperate regions and is commonly known as 'yam family', represented by a single genus *Dioscorea* (Hutchinson, 1959). The genus is one of the largest groups among monocotyledons and represents about 850 species

distributed in three centres of diversity namely South Africa, South East Asia and Latin America (Mabberley, 2005). The members are represented by herbaceous twining climbers, devoid of tendrils and mostly dioecious. The name 'Yams' has been more widely applied collectively to the species *Dioscorea* in its true sense in American literature. However, the word is commonly used for sweet potatoes also in the US. Yams are often confused with several of the edible aroids such as, *Colocasia, Alocasia and Xanthosoma* species, which are more properly referred to as taros, cocoyams and tannia, respectively. The name has also been applied to the arrow root (*Maranta arundinacea*) and in fact almost any edible starchy root, tuber or rhizome that are grown within the tropics has often been described as a yam. The term 'Yams' used here is most widely used for all members of the monocotyledonous family Dioscoreaceae or the 'yams' are any economically useful parts of the botanical genus *Dioscorea* or the tubers or rhizomes of these plants (Coursey, 1967a).

Usually, the members of the genus *Dioscorea* inhabit the forest margins and open areas up to 3500 m above mean sea level. The ariel stem twines on the neighbouring vegetation and rarely possess prickles but lack tendrils. The leaves are with variable phyllotaxy and are distinctly petiolate. Bulbils, the ariel propagules are also present in many of the species. The plants are usually dioecious and the inflorescences are spicate with many or few actinomorphic flowers. The underground stem is the most important characteristic feature, which is variously produced as by lateral hypertrophy of hypocotyl region or by hypertrophy of internode above the cotyledons.

Economic importance of the genus

Economically the genus *Dioscorea* occupies the third position as the most important food crop in the world next to cereals and pulses. The global production is estimated at about 56,000 million tonnes (FAO, 2012). Yam is a major staple food in various parts of the world especially in many tropics and subtropical regions (Cooke et al., 1988). It is mainly cultivated in South East Asia, Africa and South America, of which Africa accounts for the production of about 95% of the world yams (FAO, 2012). In South Pacific, the yam is a very popular and important food crop with its consumption being more than 200 kg/inhabitant per year (Bourret, 1973). It is used extensively for consumption by cooking, frying, boiling, roasting, or processing into flour for long time storage (Coursey, 1967a; Bourret, 1973). Even the toxic *D. hispida* and *D. bulbifera* are consumed after detoxification (Barrau, 1956b). Yams such as *D. pentaphylla* and *D. esculenta* are also cultivated traditionally to feed pigs in New Caladonia (Bourret, 1973.).

Apart from being used as food, certain species of yams like *D. deltoidea* and *D. floribunda* are important sources of pharmaceutically active compounds used in the production of contraceptives (Degras, 1993). The tubers of *D. composita* (Cruzado et.al., 1965), *D. deltoidea* (Barua et.al., 1954), *D. floribunda* (Cruzado et.al., 1965; Singh et.al., 1995), D. *hispida* (Anzaldo et.al., 1956); *D. prazeri* (Barua et.al., 1954; Barrau 1956a) are considered as the chief plant source of sapogenic precursors of cortisone and steroidal hormones. The tubers of some species contain tannins that are used by the Chinese to tan sails, fishing nets, stupefaction etc. (Ayensu, 1972, 1981). The poisonous principle found in the tuber is mainly of saponins (Burkill, 1935; Coursey, 1967b).

The tubers of *Dioscorea* deserve a special attention in the developing countries where the world's poorest and most food insecure population live and look to these tubers as a source of food, nutrition and income due to its inherent ability to produce large quantities of dietary energy in extreme conditions where other crops fail (Alexandratos, 1995). Therefore, in many regions of the world, yams are considered as a major food crop and it plays an important role not only in the nutrition but also is integrated to the cultural life of the people.

General characters of *Dioscorea*

Dioscorea exhibits morphological characters common to both monocots and dicots. Therefore, these characters are detailed for identification of this genus in the field.

Tubers

The underground part is the tuber which is usually produced by the hypertrophy of the hypocotyl or that of the internodes above the cotyledons producing annual shoots. The tubers grow about 4 to 5 meters in length and about 3 – 50 kg in weight, deeply buried or near the surface of the soil. The size and shape of the tuber differs according to the different species. They may be solitary, clustered, globose, cylindrical, fibrous or starchy: sometimes covered with numerous long rootlets, or smooth. The skin is comparatively thin, flesh white to lemon yellow or purple in colour. The tubers may be

stalked or sessile and are usually replaced annually, but in some species they are perennial.

Roots

The genus has a comparatively weak root system. The development of roots begin from the commencement of the growing season with the emergence of several thick long roots from the head or from the rhizomatous end of the tubers. They grow rapidly and ensure that the developing plant is firmly held in the ground. These roots are normally unbranched and may extend to considerable distance. Later, during the annual development of the plant, a mass of thinner, branching fibrous roots are also produced. In some species, the roots especially those which are near the surface of the ground are armed with spines.

Stems

The aerial stem grows to 40 – 50 meters in length, woody at base, sometimes hairy and twines to the right or left direction. The direction of twinning is specific and constant for a species. The stems are annual, and are renewed at the beginning of the growing period and drys away with the onset of dormancy. Climbing is entirely by means of the twinning of the stem and it has no tendrils or other specialized organs. They branch freely in most species. The stems of many species are armed with spines, which not only protect the plant from wild animals but also assist in supporting the stem on the host plants. Some species have longitudinal ridges of the stem, which help prevent them from slipping off from the support.

Leaves

The leaves are usually simple, rarely compound, alternate, opposite or sub – opposite with reticulate venation. The compound leaves are 3 – 7 foliolate, with simple lamina, entire or lobate, broadly ovate – cordate, acute or acuminate and with 3 – 15 converging veins. The possession of opposite leaves has significance and is constant within the individual species of the genus. The leaves are petiolate, glabrous or pubescent. The petiole is comparatively long with a pulvinus at both ends, twisted and often with stipule – like flanges on either side of the base. The petiole may be inflated, channelled above and apparently lack a sheathing base. The type of ptyxis is conduplicate in *Dioscorea* (Cullen, 1978).

Many species produce bulbils on the axis of the leaves, and are specially adapted for vegetative propagation. Under natural conditions they have the appearance and morphology of a condensed tuber, usually smaller than the tuber, but exceptions are there.

Inflorescence and flowers

The inflorescences are axillary spikes, and consists of many or few flowers. Flowers are small, unisexual, epigynous, regular and actinomorphic, generally being greenish or brown, sometimes white or creamy. The bracts and bracteoles are ovate, acute or acuminate. The tepals are 6 in number and are arranged in two whorls of three each, ovate, acute or acuminate, sometimes pubescent. Sepal nectarines are usually present (Grassmann, 1884; Daumann, 1970) and a nectar secreting disc has also been reported in a Bolivian species of *Dioscorea* (Huber, 1969). Stamens are six in number, free or connate, with short filaments, inserted at the base of the perianth lobes; anthers are basifixed and shows monocotyledonous type of anther wall formation (Dahlgren and Clifford, 1982). Pistillode is three – ridged, thick and fleshy at the centre. Ovary is inferior and trilocular. Carpels are fused only in the ovary region or basal parts thereof. The style is apically two or three branched. Ovules are two in each locule, and anatropous; placentation is axile. Staminodes are occasional. Fruits are capsular, orbiticular or oblong, flattened, usually three – winged and loculicidal. Seeds are two, compressed, with membranous wings.

Materials and Methods

The study was carried out to unravel the species complex that exists for quite long due to overlapping morphological characters. The live specimens of different species were introduced as part of *ex – situ* conservation for maintaining the genetic stock in the long run. Therefore, the area of the present study covered the whole Western Ghats, which is a chain of unbroken mountains in the Western Peninsular India extending from Tapti river valley in Gujarat to Kanyakumari in Tamil Nadu, is about 1600 km long in the North – South direction (Fig. 1). The only gap in this chain is the Palghat Gap. The region lies between 8°20'-21" N latitudes and 73°-77°E longitudes. The height varies from 300-1500m excluding certain isolated peaks. The highest point is Anamudi peak at 2695m, known as the south of Himalayas, situated in Kerala state. From North to South, the ghat passes through the states of Gujarat, Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala. There are several rivers originating in

the ghats and even though major rivers like Godavari, Krishna and Cauvery flow eastwards, the general drainage of the ghats is towards the west-emptying into Arabian Sea. It receives about 60% of the annual rainfall during South-West monsoon in June-August; 25% during North–East monsoon in September-November and the remaining 15% during summer months. The average rainfall varies from 2500mm in the north to 7000 mm in the southern region. This is due to delayed arrival of South-West monsoon in the north and an earlier withdrawal, cutting short the rainy days. The mean annual temperature is around 24°C in the North and in the South where rainfall is more; the mean annual temperature is about 20°C (Pandurangan and Pushpangadan, 1997).

Fig.1. Map of Western Ghats showing the area of collection

Extensive survey was conducted in the Western Ghats in different seasons for collecting different species of *Dioscorea*. Specimens were collected in flowering and fruiting conditions preferably in quadruplicate and relevant field notes on them were recorded in the field book then and there itself. Special attention was paid to gather data pertaining to habit, habitat, altitude and other features like colour of the flowers, fragrance, indumentums etc which cannot be deduced from the examinations of the herbarium specimens. The photographs of the specimens were also taken. The taxonomic identities of the collected materials were confirmed with the help of various regional floras and also by consulting with authentic specimens depositories in various National Herbaria like Central National Herbarium, Kolkata (CAL); Forest Research Institute Herbarium, Dehra Dun (DD), Blatter Herbarium, St. Xavier's College, Bombay (BLAT); Botanical Survey of India, Pune (BSI); Botanical Survey of India Northern Circle, Dehra Dun (BSD); Botanical Survey of India, Industrial Section, Kolkata (BSIM); Madras Herbarium, Coimbatore (MH); Tropical Botanic Garden and Research Institute Herbarium, Trivandrum (TBGT); Herbarium of Calicut University (CALI); Herbarium of National Botanical Research Institute, Lucknow, Presidency College Herbarium, Madras and also in consultation with the regional herbaria of Kerala Forest Research Institute (KFRI) Thrissur, Madras Christian College herbarium, M. S. Swaminathan Institute herbarium, Wayanad.

Specimens for herbarium were made following the standard method suggested by Fosberg and Sachat (1965), Jain and Rao (1977), Bridson and Forman (1991). The specimens were deposited in the Jawaharlal Nehru Tropical Botanic Garden and Research Institute herbarium (TBGT). The specimens were also preserved in FAA for further studies in the laboratory. Tubers, seeds and bulbils were also collected during the collection trips and planted the same in the Jawaharlal Nehru Tropical Botanic Garden and Research Institute Palode, Trivandrum for further studies.

In the laboratory, the specimens were carefully examined, under zoom stereomicroscope on the morphological characters of both aerial and underground parts. Micromorphological characters were observed under a compound research microscope. Illustrations were drawn using camera Lucida (Leica, Germany).

Observations on venation pattern were done after clearing the leaves. Clearing was done by immersing leaves in 10% KOH in a petri-dish for about 12 hours at 60°C and washing in running water. The specimens were stained with safranin. Excess safranin was removed by washing again in water. The specimens were then dried and mounted on a butter paper and examined with a zoom stereomicroscope and camera Lucida illustrations were made.

Results and Discussion

Systematic analysis

The genus *Dioscorea* is represented by dioecious plants. The flowering of male and female plants is at different times. Phenology of the same species in different localities are highly variable due to environmental and altitudinal variations. The various taxa are mostly distributed in the moist deciduous or semi evergreen forests, forest fringes, forest plantations etc. In the forests with thick canopy, the genus is not well represented.

Earlier workers reported 16 species and six varieties from Western Ghats (Gamble, 1935; Nayar et. al., 2014). During the course of the present survey, a total of 57 taxa have been collected of which, 21 species and 27 varieties have been identified (Fig. 2 and 3). The remaining nine taxa are imperfectly known, owing to the lack of either male or female or both male and female flowers. However, based on anatomy, these nine taxa are being proposed as new species and provisionally recognized them. The direction of twining of the stem, size and shape of the tuber, phyllotaxy of the leaves, arrangement of the flower buds on the rachis impart a better insight into the species variation and species delimitation. The distribution pattern, altitude, uses, number and shape of tubers, stem and flesh colour, flesh texture, position of tubers were noted for analysis (Tables 1, 2, 3, 4, 5 and 6).

The distribution analysis showed that 13 species were having restricted distribution in Western Ghats, seven had wider distribution and one species - *D. wightii* was strictly endemic to Southern Western Ghats (Table 1). Among the wider distribution, species such as *D. alata, D. esculenta* and *D. rotundata* are under extensive cultivation. *D. esculenta, D. rotundata, D. composita* and *D. floribunda* were of exotic origin. *D. bulbifera* and *D. pentaphylla* were both cultivated and wild. The occurrence of a particular set of more wild species in a well defined geographical region provides an insight into

Table 1. *Dioscorea* species of Western Ghats: altitude distribution and uses

Sl. No.	Species name	Altitude(m)	Distribution	Uses	Bulbils
1	*D. alata* L.	100-900	Wide	Edible	Present
2	*D. anguina* Roxb.	950-1500	Restricted	Edible	"
3	*D. belophylla* Voight	700-850	Restricted	Edible	"
4	*D. bulbifera* L.	0-1000	Wide	Edible	"
5	*D. composita* Hemsel	50-800	Restricted	Edible/Medicinal	Absent
6	*D. esculenta* (Lour.) Burkill	0-700	Wide	Edible	"
7	*D. floribunda* M.	50-800	Restricted	Edible/Medicinal	"
8	*D. glabra* Roxb.	100-1500	Restricted	Edible	"
9	*D. hamiltonii* Hook. f.	500-1000	Restricted	Edible	Present
10	*D. hispida* Dennst.	100-900	Restricted	Edible/Medicinal	Absent
11	*D. intermedia* Thwaites	100-1500	Restricted	Edible	"
12	*D. jacquemontii* Hook. f.	700-2500	Restricted	Edible	Present
13	*D. kalkaprasadii* Prain and Burkill	700-2500	Restricted	Edible	"
14	*D. oppositifolia* L.	100-2000	Wide	Edible	Absent
15	*D. pentaphylla* L.	0-1000	Wide	Edible	Present
16	*D. rotundata* Poir.	0-850	Restricted	Edible	Absent
17	*D. spicata* Roth.	3000-5000	Restricted	Edible	"
18	*D. tomentosa* Koenig ex Spreng	100-1800	Wide	Edible/Medicinal	"
19	*D. vexans* Prain and Burkill	100-900	Restricted	Edible	"
20	*D. wallichii* Hook. f.	0-1000	Wide	Edible	"
21	*D. wightii* Hook. f.	500-700	Endemic	Edible	"

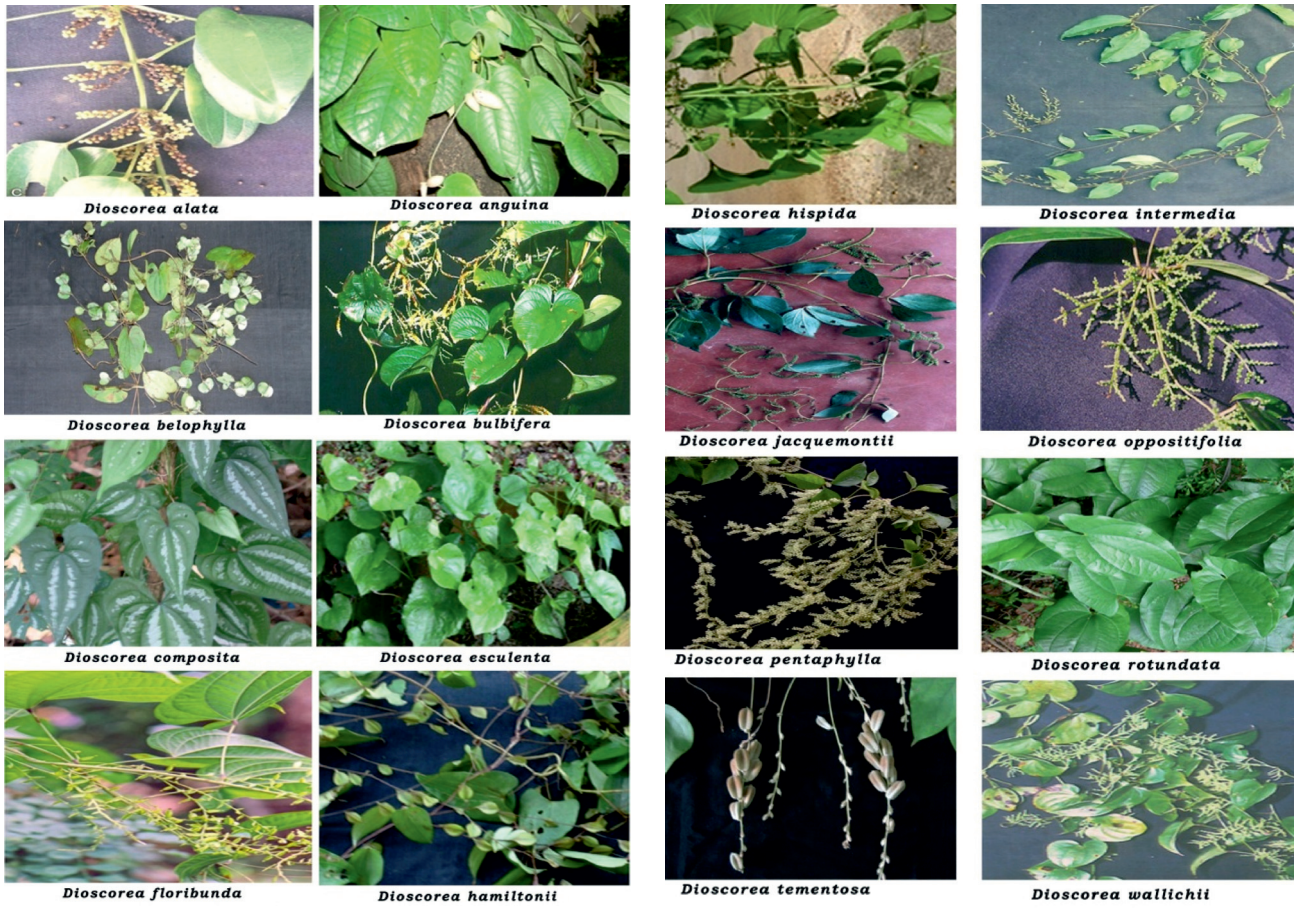

Fig.2. Species of *Dioscorea* in Western Ghats

the possible origin of the genus. Among the 21 species, *D. hispida, D. belophylla, D. hamiltonii, D. glabra, D. spicata* could be treated under rare category because of their restricted distribution in Western Ghats. Analysis of the presence of bulbils on these 21 taxa showed that 13 were without bulbils.

The nature of twining of the stem was the most important taxonomic character of the constituent species of the genus. The direction of twining of the stem was constant for a species, and the genus was divided into two groups with the stem twining to the left, and to the right (Table 2).

The analysis showed that seven species namely *D. bulbifera*, *D. esculenta, D. hispida, D. jacquemontii, D. kalkaprasadii, D. pentaphylla* and *D. tomentosa* were with stem twining to the left. Among them, *D. esculenta* was a cultivated one while all others were wild. Out of the seven left twining species, five were with compound leaves and two with simple leaves namely, *D. bulbifera* and *D. esculenta*. The remaining 14 species were with stems twining to the right and *D. alata* and *D. rotundata* were the cultivated species of this group. The occurrence of dextral (right) twining species of *Dioscorea* out numbered the sinistral (left) twining species (Table 2). It was believed that the left and the right twining character is genetically controlled. The presence or absence of prickles on the stem is also a diagnostic character of some species of the genus. Among the taxa studied, 11 were with prickles and ten were without prickles (Table 2). The prickles help the plant to climb up the support and protect them from slipping down. The prickles were either curved or straight. The presence or absence of pubescence on the stem, leaves, petiole, rachis and inflorescence were also characteristic feature of some of the taxa. Out of the 21 taxa, 17 were without pubescence on the stem and the rest four species viz., *D. anguina*, *D. hispida, D. pentaphylla* and *D. tomentosa* had pubescence (Table 2). Among these four species, three belonged to the group where the stem twined to the left with compound leaves and the other one, *D. anguina* with

Fig.3. Tubers of different species of *Dioscorea* in Western Ghats

Table 2. Analysis of occurrence and stem characters of *Dioscorea*

Sl. No.	Species name	Occurrence	Twining	Pubescence	Spines
1	*D. alata* L.	C	R	A	A
2	*D. anguina* Roxb.	W	R	P	A
3	*D. belophylla* Voight	W	R	A	A
4	*D. bulbifera* L	C/W	L	A	A
5	*D. composita* Hemsel	C	R	A	A
6	*D. esculenta* (Lour.) Burkill	C	L	A	P
7	*D. floribunda* M.	C	R	A	P
8	*D. glabra* Roxb.	W	R	A	P
9	*D. hamiltonii* Hook .f.	W	R	A	A
10	*D. hispida* Dennst.	W	L	P	P
11	*D. intermedia* Thwaites	W	R	A	A
12	*D. jacquemontii* Hook. f.	W	L	A	P
13	*D. kalkaprasadii* Prain and Burkill	W	L	A	P
14	*D. oppositifolia* L.	W	R	A	A
15	*D. pentaphylla* L.	C/ W	L	P	P
16	*D. rotundata* Poir.	C	R	A	P
17	*D. spicata* Roth.	W	R	A	P
18	*D. tomentosa* Koenig ex Spreng	W	L	P	P
19	*D. vexans* Prain and Burkill	W	R	A	P
20	*D. wallichii* Hook. f.	W	R	A	A
21	*D. wightii* Hook. f.	W	R	A	A

Note: R- Right; L- Left; A- Absent; P- Present; C- Cultivation; W- Wild

the stem twining to the right with simple leaves. The presence of ridges on the stem was also a good taxonomic character which could be used for identification and delimitation of the species and varieties. Seventeen were without ridges and four with ridges. Of these four species with ridged stems, two species viz., *D. bulbifera* and *D. alata* were with ridges which formed wings and the other two taxa namely *D. vexans* and *D. hamiltonii* had ridged stem without wings.

The study confirmed that the species twining to the left was always with reflexed capsules (Table 3). The plants were with three types of phyllotaxy - alternate, opposite, or alternate and opposite. The study identified, nine taxa with alternate leaves, only one with opposite leaves, and the remaining 11 had both alternate and opposite leaves (Table 3). The simple and compound type of leaves was also considered as diagnostic features. Among the 21 species, 16 were simple leaves and five had compound leaves. The inflorescences were mainly axillary spikes or were present on leafless branches. Three species viz., *D. alata, D. belophylla* and *D. hamiltonii* were observed with inflorescence having zig-zag rachis and the rest were with straight rachis. The morphology and position of the capsules also provides important diagnostic features in the delimitation of the species as 14 were with pendant capsules and seven with reflexed capsules.

The constituent species of the genus exhibited variation in the morphology of tubers, their size, shape, skin colour, flesh colour, texture, presence or absence of long bristle like roots over the tuber, position of the tuber in the soil etc. All these characters were stable and species specific. Twelve species had cylindrical / elongated tubers, two had globose or oblong tubers, two were globose / pyriform, one was exclusively globose, and one had elongated oblong and three were not known (Table 4). In all the 21 species, the tubers of 15 species were not covered with bristle-like roots; three were with numerous bristle like roots and the remaining three were yet to be observed.

Table 3. Leaf and fruit characters of *Dioscorea*

Sl. No.	Species name	Leaf position	Leaf type	Fruit direction
1	*D. alata* L.	Al/Op	Simple	Downwards
2	*D. anguina* Roxb.	Al/Op	Simple	Downwards
3	*D. belophylla* Voight	Al/Op	Simple	Downwards
4	*D. bulbifera* L.	Al	Simple	Upwards
5	*D. composita* Hemsel	Al	Simple	Downwards
6	*D. esculenta* (Lour.) Burkill	Al	Simple	Upwards
7	*D. floribunda* M.	Al/Op	Simple	Downwards
8	*D. glabra* Roxb.	Al/Op	Simple	Downwards
9	*D. hamiltonii* Hook .f.	Al	Simple	Downwards
10	*D. hispida* Dennst.	Al/Op	Compound	Upwards
11	*D. intermedia* Thwaites	Al	Simple	Downwards
12	*D. jacquemontii* Hook. f.	Al	Compound	Upwards
13	*D. kalkaprasadii* Prain and Burkill	Al/Op	Compound	Upwards
14	*D. oppositifolia* L.	Al	Simple	Downwards
15	*D. pentaphylla* L.	Op	Compound	Upwards
16	*D. rotundata* Poir.	Al/Op	Simple	Downwards
17	*D. spicata* Roth.	Al	Simple	Downwards
18	*D. tomentosa* Koenig ex Spreng	Al/Op	Compound	Upwards
19	*D. vexans* Prain and Burkill	Al	Simple	Downwards
20	*D. wallichii* Hook. f.	Al/Op	Simple	Downwards
21	*D. wightii* Hook. f.	Al/Op	Simple	Downwards

Note : Al–Alternate; Op–Opposite

Table 4. Tubers of *Dioscorea*-1

Sl. No.	Species name	No. of Tubers	Shape	Covered with roots or not
1	*D. alata* L.	One/More	Gl/Ob/Lo	No
2	*D. anguina* Roxb	One/Two	El	No
3	*D. belophylla* Voight	Single	Cy	No
4	*D. bulbifera* L.	Single	Gl/Py	Yes
5	*D. composita* Hemsel	NK	NK	NK
6	*D. esculenta* (Lour.) Burkill	Several	Gl/Ob	No
7	*D. floribunda* M.	NK	NK	NK
8	*D. glabra* Roxb.	One/More	El	No
9	*D. hamiltonii* Hook. f.	One/Two	Cy	No
10	*D. hispida* Dennst.	Several	Gl	Yes
11	*D. intermedia* Thwaites	Two/Three	El	No
12	*D. jacquemontii* Hook. f.	Single	El/Ob	Yes
13	*D. kalkaprasadii* Prain and Burkill	Single	El	No
14	*D. oppositifolia* L.	Single	Cy	No
15	*D. pentaphylla* L.	one/two	Gl/Py	No
16	*D. rotundata* Poir.	Single	Cy	No
17	*D. spicata* Roth.	Single	El	No
18	*D. tomentosa* Koenig ex Spreng	Several	Cy/El	No
19	*D. vexans* Prain and Burkill	Several	El	No
20	*D. wallichii* Hook. f.	Several	Cy/El	No
21	*D. wightii* Hook. f.	NK	NK	NK

Note: Gl- Globose; Ob- Oblong; Lo- Long; El- Elongated; Cy- Cylindrical; Py- Pyreform; NK- Not Known (Used herbarium specimens from Kew and TBGT for species description without tubers)

Table 5. Tubers of *Dioscorea*-2

Sl. No.	Species name	Skin colour	Flesh texture	Flesh colour
1	*D. alata* L.	Light brown	Tender starchy	Lp/Wh
2	*D. anguina* Roxb.	Tawny orange	Tender starchy	Ly
3	*D. belophylla* Voight	Pale yellow	Tender starchy	Wh
4	*D. bulbifera* L.	Soil colour	Hard starchy	Wh/Ly
5	*D. composita* Hemsel	Brown	Rough	Wh/Ye/Pi
6	*D. esculenta* (Lour.) Burkill	Brown	Tender starchy	Wh
7	*D. floribunda* M.	White/brown	Semi woody	White
8	*D. glabra* Roxb.	Earth coloured	Tender Starchy	Wh
9	*D. hamiltonii* Hook. f.	Dark black	Tender starchy	Wh
10	*D. hispida* Dennst.	Straw colour	Hard starchy	Wh/Ly
11	*D. intermedia* Thwaites	Creamy	Tender starchy	Wh/Pu
12	*D. jacquemontii* Hook. f.	Brown	Hard starchy	Wh
13	*D. kalkaprasadii* Prain and Burkill	Brown	Hard starchy	Wh/Ye
14	*D. oppositifolia* L.	Brown yellow	Tender starchy	Cmy
15	*D. pentaphylla* L.	Brown	Hard/Soft/ Starchy	Ly/Pc
16	*D. rotundata* Poir.	Brown	Soft Starchy	Wh
17	*D. spicata* Roth.	Pale Brown	Soft Starchy	Wh
18	*D. tomentosa* Koenig ex Spreng	Brown	Soft and fibrous	Bty
19	*D. vexans* Prain and Burkill	Brown	Soft Starchy	Wh
20	*D. wallichii* Hook. f.	Brown	Soft and Fibrous	Wh
21	*D. wightii* Hook. f.	NK	NK	NK

Note: Lp- Light purple; Wh- White; Ly- Lemon yellow; Pu- Purple; Ye- Yellow; Cmy- Creamyellow; Pc- Pale Cream; Bty- Butter Yellow; NK- Not Known (Used herbarium specimens from Kew and TBGT for species description without tubers)

The study gave importance to the systematic analysis of the tubers on the skin colour, flesh texture, and flesh colour as detailed (Table 5). Most of the tubers were tender and starchy.

Presence or absence of stalk on the tubers was a distinct characteristic feature of the species. A total of ten taxa were with sessile tubers, ten with stalk and one was not known (Table 6). All the taxa (21 spp., 27 varieties and nine new species) identified from the Western Ghats were highly edible and medicinal.

The plants were commonly dioecious and the phenology of the different species was also different at different times in the same area. The flowering of male plants began early, long before the onset of flowering of the female plants. This might be the reason for most of them been sterile in nature. The onset of male flowers normally started from May – August and might not last for a long period. But the flowering of the female plants began only after the month of September. Some of the unidentified specimens collected during the study had female inflorescence even in April - May. The male inflorescence might be in a straight axis or in a zigzag axis just like *D. alata*. The flowers might be borne on leafless terminal or axillary branches. Depending upon the species, they may or may not be highly branched. Ahmedullah and Nayar (1986) erroneously reported that three species namely, *D. belophylla, D. kalkaprasadii and D. wightii* were endemic to peninsular India. The present study confirmed that *D. wightii* is the only species endemic to Peninsular India and the other two species were extended to various parts of the country (Nayar, et. al., 2014). *D. bulbifera, D. pentaphylla, D. tomentosa, D. wallichii* and *D. oppositifolia* were well distributed in the wild in almost all places. *D. alata* is commonly cultivated for its tubers. *D. intermedia* Thw., a Sri Lankan species was identified during the study

Table 6. Tubers of *Dioscorea*-3

Sl. No.	Species name	Position in the soil	Tuber on stalk / not
1	*D. alata* L.	Deeply buried/Surface	Sessile
2	*D. anguina* Roxb	Deeply buried	Stalked
3	*D. belophylla* Voight	Deeply buried	Stalked
4	*D. bulbifera* L.	Near the surface	Sessile
5	*D. composita* Hemsel	Deeply buried	Sessile
6	*D. esculenta* (Lour.) Burkill	Near the surface	Stalked
7	*D. floribunda* M.	Deeply buried	Sessile
8	*D. glabra* Roxb.	Deeply buried	Stalked
9	*D. hamiltonii* Hook. f.	Deeply buried	Stalked
10	*D. hispida* Dennst.	Near the surface	Sessile
11	*D. intermedia* Thwaites	Deeply buried	Sessile
12	*D. jacquemontii* Hook. f.	Deeply buried	Stalked
13	*D. kalkaprasadii* Prain and Burkill	Deeply buried	Stalked
14	*D. oppositifolia* L.	Deeply buried	Sessile
15	*D. pentaphylla* L.	Deeply buried	Stalked
16	*D. rotundata* Poir.	Near the surface	Sessile
17	*D. spicata* Roth.	Deeply buried	Stalked
18	*D. tomentosa* Koenig ex Spreng	Near the surface	Sessile
19	*D. vexans* Prain and Burkill	Deeply buried	Stalked
20	*D. wallichii* Hook. f.	Deeply buried	Sessile
21	*D. wightii* Hook. f.	NK	NK

NK- Not Known (Used herbarium specimens from Kew and TBGT for species description without tubers)

which is intermediate in spike length between *D. spicata* and *D. oppositifolia*. Since the different species of the genus *Dioscorea* are important genetic resources for food, feed and medicine, it is necessary to locate their viable population. The status of some of the members of the genus became vulnerable due to over exploitation. It was observed that the species are being depleted rapidly due to excessive collection for its medicinal tubers without any attempt to replenish its natural population in forest area. Multiplication of the species and introduction in botanic garden needs to be taken up. A gene bank of all wild yams in the country should be considered on a priority basis, at suitable places. The taxonomy of quite a few species in this genus is considered to be problematic (Prain and Burkill, 1936, Velayudhan et.al., 1998), due to its highly continuous variability of morphological characters especially in aerial parts such as leaves and bulbils. This continuous variation makes it difficult for "Linnaean taxonomists" to segregate distinctly the various taxa of this genus. However, the communities who depend on wild *Dioscorea* species for their food classified each member of this genus based on characters of its edibility, uses and application. Such classification of taxa based on use, value and application by ordinary people, called folk taxonomy. Balakrishnan et. al. (2006) discussed folk taxonomy and their relation to the genetics of crops and it has been shown that inter specific folk taxonomies were often biologically accurate. Folk identification and classification to a certain extent also helps in estimating genotypic diversity (Boster, 1985; Balakrishnan et. al., 2006). The present study depends on a wide range of information not only on the characteristic features of the taxa in question, but also on location in certain habitats and seasonal periods. This type of ethno-botanical approach can help botanists to delimit polymorphic taxa with continuous variation, particularly in case of species with use values.

Key to the species: A dichotomous key was prepared based on morphology for identification of species and the same is given below.

1a. Stem winged or prickled or armed; petiole variously winged or rarely wingless…….. 2
2a. Stem 4 - 8 winged…….. *D. alata*
2b. Stem 6 - 8 winged or wingless, but prickled or armed……3
3a. Stem up to 6 winged……..... 4
3b. Stem with 8 long wings; midrib single winged; petiole 5 winged; leaves hastate; cordately ovate or lanceolate; fruits with 5 rounded wings…….. *D. hamiltonii*
4a. Midrib and petiole 2 winged; leaf shallowly cordate, sagittate with basal angular lobes… *D. belophylla*
4b. Midrib not winged; petiole with 5 unequal wings; leaves broadly ovate; ……... *D. bulbifera*
1b. Stem wingless, no prickles, no thorns or rarely prickled; petiole wingless……5
5a. Leaf trifoliate, glabrous, young ones pubescent; major veins with prickles on the abaxial side; petiole and stem prickled; male inflorescence compound…….. *D. hispida*
5b. Leaf 3 - 5 foliolate, hirsutely pubescent or tomentose; prickles absent; male inflorescence simple……... 6
6a. Bulbils present; leaves of the upper shoot simple, lower part of the shoot compound; leaflets hirsutely pubescent below; hairs rusty red or white, not silky; capsule glabrous; tubers not clustered……. *D. pentaphylla*
6b.Bulbils absent; leaves simple or compound all throughout; leaflets tomentose; hairs grey silky; capsule tomentose; tubers clustered ……. 7
7a.First formed leaves simple, later formed leaves compound; lower surface of the leaflet snow white; stem with straight or curved prickles…..... *D. tomentosa*
7b.Both first and later formed leaves compound, hirsute……..……..8
8a.Leaves 5 - 7 foliolate, lamina often irregularly divided …….. *D. kalkaprasadii*
8b.Leaves less than 5 foliolate, lamina not divided…..……...…9
9a.Stem woody, glabrous, green; 2 prickles at the node; leaves 3 - 5 foliolate……*D. jacquemontii*
9b.Stem neither prickled nor armed……...…...10
10a.Leaves alternate, ovate, glabrous on both sides; veins 3 - 7…....…..…*D. spicata*
10b.Leaves opposite, ovate-cordate, elliptic or reniform, glabrous adaxially; veins more than 7…....…...11
11a.Leaves cordate, tomentose below, glabrous above, lamina 6-13 × 7-15 cm; bulbils absent…... *D. esculenta*
11b. Leaves ovate, reniform; glabrous on both sides lamina 14.5 × 11cm; bulbils present…..……12
12a. Leaves reniform, suborbicular, coriaceous, lamina 5 – 12 × 4 – 11 cm; petiole 5-9 cm long; articulated at the base, thorny; male inflorescence on leaflets branches.....*D. wallichii*
12b.Leaves ovate, cordate at base, lamina 12 - 14.8 × 9 - 5.5 cm; petiole 5 - 8.5 cm long, not articulated; inflorescence on leafy or leafless branches.....13
13a.Leaves-ovate or ovate-lanceolate, hirsute, 7.8 - 14.5×4 – 9 cm; petiole 4.5-8.5 cm long….. *D. floribunda*
13b. Leaves cordate, glabrous ……..…14
14a. Leaves alternate, cordate on the base, glabrous; 10 – 12 × 5 - 5.5 cm; bulbils absent; petiole 5 cm long, purple, semiterete……..……..*D. wightii*
14b.Leaves opposite with variable size, petiole terete……..15
15a.Leaves strictly opposite with white patches on the lower side, upper side dark green ..... *D. composita*
15b.Leaves varies from opposite to alternate, upper side lacking white patches…...……16
16a.Stem with shallow longitudinal ridges; leaves opposite or subopposite, ovate – cordate, sometimes hastate, acuminate, lamina 15 × 10 cm, brownish tawny, leaf margins tawny…….*D. vexans*
16b. Stem not ridged; leaves alternate, glabrous or pubescent; not brownish, tawny……...17
17a.Leaves densely pubescent; petiole more than 7 cm long, lamina cordate at base; veins not prominent; bulbils as big as the human fist ……..… *D. anguina*
17b.Leaves glabrous; petiole less than 7 cm long, bulbils absent, leaf not cordate, veins prominent;....18
18a. Leaves ovate - elliptic, longer than breadth….19
18b.Leaves cordate, broader than length…..…....20
19a. Petiole up to 1.5 cm long, leaf margins not cartilaginous, lamina coriaceous; 3–nerved.... *D. intermedia*
19b.Petiole up to 3 cm long; leaf margin cartilaginous, lamina not coriaceous; veins 3-5..... *D. oppositifolia*
20a.Leaves invariably opposite, deltoid, apex acuminate lamina glabrous, thick; fruits prominently 3 winged……*D. rotundata*
20b.Leaves vary from alternate or sub-opposite, deeply cordate, lamina thin and curls upon the midrib on drying; fruits short winged…….....…… *D. glabra*

The practicing taxonomists faced a lot of problems in identification of different species of *Dioscorea* because of their overlapping morphological characters. The keys provided by the earlier workers were inadequate and hence many economically important species were misidentified both in the herbarium and field. To overcome these problems, a fresh survey had been conducted throughout the Western Ghats and the collected specimens were critically examined and determined their taxonomic identity with established protocol. A user friendly dichotomous key had been prepared for identifying all the species currently available in the Western Ghats. The study delimited 21 species, 27 varieties and proposed nine new species. In short, the investigation added further knowledge on 14 species and 21 varieties growing in the Western Ghats which are overlooked by the researchers.

The study observed that most of the wild species produced male and female flowers at different times and hence affects the fruit set. It was also observed that in many cultivated species the production of female flowers and seed set were almost ceased. This was attributed to the long history of vegetative propagation and the seedlings produced by this method has shown considerable variation in the degree of sterility such as withering of inflorescence completely or nearly so, abscission of flowers on spikes, lack of well developed flowers, poor pollen production, incomplete development of capsules etc. Such reproductive abnormalities spelt the doom on the sexual reproductive process which led to genetic uniformity in many species and eventually face uncertain future from the evolutionary point of view.

Based on the investigation, it is understood that many species are sparsely distributed and difficult in getting both the sexes. To improve agricultural production of yams it is essential to maintain the germplasm of these species in *ex-situ* condition in Botanic Gardens, Agricultural Universities and research institutes like CTCRI, KAU, MSSRF and NBPGR.

Conclusion

In spite of its economic importance, the group has not been evaluated taxonomicalfor the last 50 years. Consequently, taxonomic treatment/delimitation of certain species is still uncertain and needs to be scientifically scrutinised. *Dioscorea* shows many morphological similarities with dicotyledons (Huber, 1969, 1977). The stem contains vessels with scalariform perforation plates that are found in many species of Magnoliflorae. The leaves are opposite in many species of *Dioscorea* which otherwise is rare in monocotyledons but fairly common in dicotyledons, although not particularly so, in Magnoliflorae. The occurrence of compound leaves in the genus resulting from irregular growth supports a possible relationship between the Taccales and the Arales (Dahlgren et al., 1985). The leaves are petiolate in *Dioscorea* and have non – sheathing base, as is normal in Magnoliflorae. Stipule – like appendages occur in *Dioscorea*, which are rare in monocotyledons but widely distributed in dicotyledons, however these are rare in Magnoliflorae. The lamina is compound in some species of *Dioscorea* and such characters are much common in dicotyledons. The venation of the leaf is reticulate in *Dioscorea* but normally such characters are typical to dicotyledons. The flowers are not particularly showy. The greenish and small to moderate size of the flowers of *Dioscorea* will agree with some Magnoliflorae dicotyledons. All these characters pave way to strongly believe that *Dioscorea* has some dubious link with dicotyledons and further studies are required to understand the evolution and the proper taxonomic status in future.

Acknowledgement

The authors wish to express sincere thanks and gratitude to Dr. (Prof.) P. Jayaraman, Director, Plant Anatomy Research Centre, West Tambaram, Chennai for his sincere support and encouragement. The first author is indebted to the Principal and Staff of Department of Botany, Maharajas College, Ernakulam for their kind co-operation and last but not least to Mr. Maxwell V, Chief Manager, State Bank of Travancore, M. G. Road, Ernakulam and also to Prannoy Anand Maxwell and Shreya Merlin Maxwell for their support.

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