Chapter 11
Cultivation and Utilization of Diosgenin-Contained *Dioscorea* Species

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Abstract The genus *Dioscorea*, family Dioscoreaceae, has 633 species, all popularly known as yam, of which approximately 137 contain the diosgenin compound. Diosgenin, a phytosteroid sapogenin, is used as a raw material for the synthesis of steroid hormones that make up several types of drugs, such as adrenal cortical hormone, sex hormone, birth control pills, anabolic hormones, among others. Diosgenin also presents pharmacological activities such as anti-inflammatory, antimicrobial, and hypoglycemic, which allows its utilization to treat several diseases such as osteoporosis, diabetes, and obesity. Currently, the amount of diosgenin extracted from yam species have decreased due to extensive harvesting and consequently decline of *Dioscorea* spp. populations, as well as the lack of adequate technologies capable of extracting this compost on a large scale. Thus, it is necessary to identify species and/or accessions of *Dioscorea* with a higher diosgenin content to attend the demand for diosgenin extraction. However, a uniform procedure for the preparation of samples and analysis of diosgenin is highly desirable. In this review, we are providing information about the origin, domestication, geographic distribution, cultivation, utilization, and medicinal properties of diosgenin-contained *Dioscorea* species.

Keywords Domestication · Geographic distribution · Medicinal properties · Saponins · Secondary metabolites · Yams

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11.1 Introduction

The word “yam” is derived from the languages of West Africa, Mande, “niam” or Temne, “enyame”, later adopted in Portuguese as “ynhame”, in Spanish as “tame”, in French as “igname”, and English as “yam” (Burkill 1938). Although this term is currently used loosely to refer to many species that produce edible roots, true yams are only those belonging to the family Dioscoreaceae, genus *Dioscorea* (Barton 2014).

The genus *Dioscorea*, of about 633 species (Couto et al. 2018), usually consists of climbing plants with underground tubers or aerial bulbs, with heart-shaped leaves, small green or white flowers and a winged capsule or berry fruit. Species of this genus are widely distributed in tropical, subtropical, and temperate regions of the world, and much is due to the time of great sailing, where Spanish and Portuguese sailors took the yam from Southeast Asia to the New World (Barton 2014).

Nutritionally, underground tubers and aerial yam bulbs are rich in vitamins A, C, and the B complex (thiamine, riboflavin, and niacin), in addition to being a good source of carbohydrates and presenting considerable levels of proteins and lipids (Oliveira et al. 2007). Regarding its medicinal properties, the low glycemic index of yam present when ingested in the diet allows its indication to diabetic people, with obesity problems, osteoporosis, among other hormonal and metabolic diseases (Siadjeu et al. 2015; Azeteh et al. 2019).

Among the compounds present in the yam species, diosgenin stands out. Diosgenin is a sapogenin widely used in the synthesis of steroid drugs discovered in 1936 by Fujii and Matsukawa (Martin 1969). After the Second World War, the growing need for steroid drugs and the high cost for obtaining this substance from an animal source led to the widespread search for plant sources of diosgenin, favoring the development of the steroid industry. This industry has been has been using mainly two species, *D. composita* Hemsl and *D. floribunda* Mart and Gal., originally from Mexico and Central America, respectively. However, other species of *Dioscorea* have been commercially exploited in the steroid industry, such as *D. sylvatica* Ecklon, from South Africa, and *D. deltoidea* Waal., from India (Martin 1969; Price et al. 2016).

Diosgenin, a bioactive phytochemical, is not only used as a raw material for the preparation of steroid drugs in the pharmaceutical industry but also in the treatment of various types of disorders, such as cancer, hypercholesterolemia, inflammation, and various types of infections (Jesus et al. 2016). Due to its pharmacological and industrial importance, several extractions and analysis procedures have been developed over the years in order to identify, isolate, and quantify natural sources of diosgenin (Jesus et al. 2016).

It is worth mentioning that studies related to prospecting for secondary metabolites in yam tubers have been restricted to a few species, despite the great diversity of Neotropical *Dioscorea* (Mignouna et al. 2009). Another limitation is the scarcity of new technologies capable of optimizing the extraction of diosgenin and large-scale synthesis of drugs produced from this compound.

Based on this context, the objective of this chapter was to present a review on the origin, domestication, genetic diversity and geographical distribution of *Dioscorea* species, with emphasis on the diosgenin-contained species, as well as to present the general molecular structure, medicinal properties, and use of diosgenin by the pharmaceutical industry.

11.2 Origin, Domestication, and Genetics of *Dioscorea* Spp.

The species of the Dioscoreaceae family occur worldwide; however, their origin is still controversial (Castro et al. 2012). The *Dioscorea* genus originated in the Laurasian Palaearctic region, between the late Cretaceous (57.7–85.9 Mya) and the Mid Eocene (47.6–49.1 Mya), with subsequent radiations to the southern regions by long-distance dispersal or migration by land bridges in the Oligocene–Miocene (33.90–5.33 Mya) (Viruel et al. 2010). Although this genus has some species in the subtropical and temperate regions, its higher frequency and diversity occur in the Neotropics, where there are around 50% of the species (Couto et al. 2018). The two main Neotropical clades in a phylogenetic analysis (Couto et al. 2018) originated between the Eocene and Oligocene: the crown age for one of the clades is 31.2 Mya (23.6–39.2 Mya) and for the other clade 28.2 Mya (19.5–37.2 Mya). In the Neotropics, the species are distributed in several environments, from dry "restinga" at sea level to Andean paramos, including the edges and interior of humid forests, natural grassland ecosystems, rupicolous areas and semi-desert environments (Couto et al. 2014). As a consequence of the great variety of environmental conditions in which they occur, *Dioscorea* spp. exhibit a wide range of ecological responses, reflected in the large morphological variability found in the family. They range from large climbing vines (40 m high) to dwarf species, can be monoecious or dioecious, and present different leaf shapes, among other distinct characters (Couto et al. 2018).

Currently, of the hundreds of existing yam species, around eleven are cultivated and contribute to food security in many countries, constituting an essential source of food in Africa, Asia, Caribbean, Pacific Islands, and South America. However, many of the wild yam species have also been crucial in times of food scarcity (Shajeela et al. 2011; Dutta 2015; Padhan et al. 2020). The cultivated species of *Dioscorea* are originated from Southeast Asia and Melanesia [(*D. alata* L., *D. esculenta* (Lour.), *D. nummularia* Lam. and *D. pentaphylla* L.)], Japan and China (*D. opposita* L. and *D. japonica* Thunb), West Africa [(*D. rotundata* Poir., *D. dumetorum* (Kunth) Pax and *D. cayenensis* Lam.)], South America (*D. trifida* L.), and Africa, Asia and Melanesia (*D. bulbifera* L.) (Azeteh et al. 2019). In addition to food value, many of these species also have sociocultural and medicinal importance for local people (Azeteh et al. 2019).

Dioscorea spp. have a history linked to human beings for thousands of years by a slow and gradual process of domestication (Ayensu and Coursey 1972). Yams are considered to be domesticated at least 10.200 BP. However, the processing of yams and other plants indicates they have been domesticated and integrated into cultivation practices by at least 7.000 to 6.500 BP (Fullagar et al. 2006). Yam domestication occurred independently in distinct times in three different continents: in Asia (*D.

alata), America (*D. trifida*), and Africa (*D. rotundata* and *D. cayenensis*) (Harlan 1992). The domestication process, implemented by yam farmers, has been described in great detail for West African species (Mignouna and Dansi 2003; Vernier et al. 2003; Scarcelli et al. 2005, 2006). The process of yam "domestication" involves the adaptation of spontaneous plants (which are plants grown without farmer´s help) to cultivation constraints without genetic changes. In this process, modifications in tuber form, size, and taste are obtained by farmers, who use only vegetative multiplication. Farmers select a spontaneous tuber for its likeness to cultivated varieties and plant it in their fields. For at least three years, farmers submit the pre-domesticated tuber to stress. If accepted by the farmers, the modified tuber is mixed with tubers of a similar variety or originates a new variety (Vernier et al. 2003; Scarcelli et al. 2005, 2006).

The genetics of yam domestication has also been well studied with morphological characters (Djedatin et al. 2017; Padhan et al. 2019) and molecular markers, such as restriction fragment length polymorphism (RFLP) (Terauchi et al. 1992), amplified fragment length polymorphism (AFLP) (Scarcelli et al. 2005, 2006), chloroplast DNA markers (Croxton et al. 2011; Barman et al. 2018), simple sequence repeat markers (SSR) (Mengesha et al. 2013; Scarcelli et al. 2017; Djedatin et al. 2017; Padhan et al. 2019), genotyping by sequence (GBS) (Girma et al. 2014), and whole-genome resequencing (Scarcelli et al. 2019).

Most of these studies have shown that yam domestication, as practiced by farmers, results in gene flow between the cultivated guinea yam species (*D. cayenensis* and *D. rotundata*) and the wild-related species, such as *D. abyssinica* Hochst. ex Kunth (originated from the savannah) and the forest species *D. praehensilis* (Benth.) A. Chev. (Terauchi et al. 1992; Scarcelli et al. 2006; Magwé-Tindo et al. 2018). However, pre-domesticated plants are not always clearly identified as belonging to either wild or cultivated species (Mignouna and Dansi 2003). Plants derived from intervarietal and interspecific hybridization also may have the same indistinction (Scarcelli et al. 2005, 2017). Girma et al. (2014) investigated the role of these two wild species plus three others concerning the origin and domestication of the two cultivated guinea yams (*D. rotundata* and *D. cayenensis*), such as *D. mangenotiana* F. Meigen, *D. togoensis* R. Knuth., and *D. burkilliana* Miege. The authors found that *D. togoensis* and *D. burkilliana* were most distant from the two cultivated species, whereas *D. abyssinica*, *D. mangenotiana*, and *D. praehensilis* were closest to cultivated yams. Using whole-genome sequencing, Scarcelli et al. (2019) found that *D. praehensilis* is the most likely progenitor of African *D. rotundata.*

In India, the relationship of several wild species with cultivated *D. alata* was also investigated using morphological traits and molecular markers (SSR). The genetic similarity analysis showed that the wild yam species such as *D. opposita*, *D. hamiltonii,* and *D. pubera* Blume had the highest genetic similarity with *D. alata* and showed their potentiality for yam improvement programs (Padhan et al. 2019). However, Sharif et al. (2020) concluded that the wild relative of *D. alata* is still unknown. Genetic analysis conducted through genotyping by sequencing of 643 greater yam (*D. alata*) accessions from four continents, using demographic inference, showed an early divergence between accessions from Mainland Southeast Asia and

Pacific, probably followed by two independent domestication events (Sharif et al. 2020). The species would then have reached the Indian Peninsula, subsequently Africa and from there the Caribbean.

Many studies on diversity and genetic structure of *Dioscorea* species have been conducted with several molecular markers in the last decade, mainly toward the cultivated species (Croxton et al. 2011; Siqueira et al. 2012, 2014; Nascimento et al. 2013; Yan et al. 2014; Ngo Ngwe et al. 2015; Silva et al. 2016, 2017; Arnau et al. 2017; Agre et al. 2019), but some studies included the wild *Dioscorea* species (Yan et al. 2013; Girma et al. 2014; Barman et al. 2018; Scarcelli et al. 2017, 2019; Padhan et al. 2019). These genetic data can contribute to the understanding with more details the plant genetic resources, especially crop wild relatives like wild yams, which are under high risks of extinction due to habitat loss, climate change, unacceptable collection practices, shifting cultivation practice and over-exploitation (Magwé-Tindo et al. (2016). For example, *D. zingiberensis* C.H. Wright, an important plant resource for diosgenin content in China (Yi et al. 2014), has its natural populations strongly declined as a result of over-exploitation (Yan et al. 2013).

11.3 Cultivation and Diosgenin-Contained *Dioscorea* Species

Yams (*Dioscorea* species) constitute the predominant starch source in sub-Saharan Africa, where food security for a growing human population is a critical issue. About 93% of total yam production of the world in 2008 was produced in five West African countries (Nigeria, Cote d'Ivoire, Ghana, Benin, and Togo) located in the traditional "Yam Zone" (Fu et al. 2011). Nigeria is the world's largest producer of yams, accounting from 70 to 76% of world production. According to the Food and Agriculture Organization report, in 2018, Nigeria produced 47.5 million tonnes of yams per year from 5.9 million hectares (FAO 2020). In other parts of the world, yam cultivation is punctual compared to African countries' production. For example, in 2018, Brazil produced 251.458 tonnes in 25.7 thousand hectares, with the highest output of yams in this country occurring mainly in the Northeast (Siqueira 2011; FAO 2020).

Cultivation and management methods for *Dioscorea* spp. have been widely discussed in the literature (Aighewi et al. 2015; Hgaza et al. 2020). However, the geographic distribution and ecological requirements of these species are still unknown, as a very limited number of studies have considered the distribution patterns of *Dioscorea* species, especially for those containing diosgenin, with very little information in the literature related to the ecological factors inherent to each species, such as climate, soil, origin, to draw an accurate map of the global cultivation region for these species (Shen et al. 2018). In general, high cost of planting materials, high labor costs, poor soil fertility, low yield potential of local varieties, pests and diseases (yam anthracnose, virus, and nematodes), and shortage of good quality yam seeds of popular landraces and released varieties have been identified as the major constraints of yam production in Africa (Aidoo et al. 2011; Darkwa et al. 2020).

Yam planting is done with tubers, although in species that generate aerial bulbils, located at the base of petioles, as in *D. bulbifera*, the bulbils can be used for planting. Yams can also be grown from seeds, although unusual, due to the difficulty in sexually reproducing some species of yams. Cultivars of some species rarely flower and produce seeds when grown in environmental conditions different from their place of origin, mainly because they need adequate edaphoclimatic conditions, as well as specific pollinating agents for the species (Hortas 2020).

Most cultivated *Dioscorea* spp. are typical of a hot and humid climate, generally resistant to drought, grown in drained soil rich in organic matter, and require direct daily sunlight for a few hours, such as *D. alata*, *D. bulbifera* and *D. esculenta.* However, some species survive well in mild weather, such as *D. opposita* (Hortas 2020).

Regarding the distribution of diosgenin-contained *Dioscorea* species, Shen et al. (2018) observed a significant occurrence of these species in Eastern Asia, Southern North America, and Southern Africa. Also, new ecological suitability areas were found to be mainly distributed in the central region of South America, in the southern part of the European and coastal regions of Oceania. The authors concluded that annual precipitation and annual mean radiation are important climatic factors and also have decisive control on the *Dioscorea* species distribution.

Of the more than 600 yam species existent, 137 of them contain diosgenin, according to Wan et al. (1994). As mentioned above, two species, *D. composita*, originated from Mexico, and *D. floribunda*, originated from Central America, are the main diosgenin producing species for the industry, although other species have also been commercially exploited, such as *D. sylvatica*, from South Africa, and *D. deltoidea*, from India (Martin 1969; Price et al. 2016). Currently, China and Mexico are the greatest world's diosgenin producers, while China is the main international supplier of diosgenin and its derivatives (Li et al. 2010; Jin et al. 2017). Several species tested for diosgenin content and their origins are listed by Martin (1969). Among these, it is worth mentioning the higher diosgenin-content species, such as *D. composite* (from Mexico), *D. deltoidea* (from India), *D. floribunda* (from Central America), *D. prazeri* var. *glauca* (author unknown) (from India), *D. spiculiflora* Hemsl. (from Mexico), and *D. sylvatica* (from South Africa) (Table 12.1, adapted from Martin 1969), four of them commercially exploited.

Many other studies have reported diosgenin content in *Dioscorea* species, such as Edwards et al. (2002) that obtained 305.7±_45.9 and 409.3±225.6 nmol/mg of diosgenin extracted from tubers, respectively, from *D. batatas* and *D. villosa* L., both species from China. Vendl et al. (2006) extracted diosgenin from the leaves of 51 accessions of *D. alata, D. batatas*, *D. bulbifera*, *D. caucasica* Lipsky, *D. cayenensis*, *D. composita*, *D. deltoidea*, *D. discolor*, *D. japonica*, *D. mangenotiana*, *D. nipponica* Makino, *D. pentaffylla*, *D. reticulate*, *D. rotundata*, *D. sansibarensis, D. sp* and *D. vittata*, showing total diosgenin content varying from 0.036% (*D. bulbifera*) to 0.926% (*D. rotundata*). The authors also found differences between accessions of the same species, for example, varying from 0.447% to 0.926% of dry weight for different genotypes of *D. rotundata.* Although diosgenin quantities from leaf samples range below the highest values for subterraneous organs, variation among diosgenin contents between different leaf samples is much lower than in tuber tissues, making diosgenin quantification of *Dioscorea* leaf material more comparable, according to Vendl et al. (2006).

The diosgenin content determined in a *D. polygonoides* Humb. & Bonpl. tuber collection from Colombia ranged from 0.02 to 2.64% (Niño et al. 2007). Again, intraspecific variability was detected in this study. Another study determined the diosgenin content from tubers of 54 accessions of *D. sparsiflora* and six accessions of *D. remotiflora*, from the state of Jalisco, in Mexico (Contreras-Pacheco et al. 2013). Diosgenin levels varied from 0.02 to 0.16 mg kg^{-1} in the dry base, also showing considerable intraspecific variation.

Diosgenin content was determined from four *Dioscorea* species by Yi et al. (2014), and the higher content was found for *D. zingiberensis* (varying from 8.67 to 19.52 mg g^{-1}), followed by *D. collettii* Hook f. (13.19 mg g^{-1}) and *D. septemloba* Thunb. (varying from 0.78 to 1.18 mg g^{-1}). Diosgenin was also detected in nine species, with *D. pubera* showing the highest value (7 mg g^{-1}), followed by *D. bulbifera* (6 mg g^{-1}), and the lowest value was found for the cultivated *D. alata* (4 mg g^{-1}) (Padhan et al. 2020).

As we have noticed in the above studies, different chemical and biological protocols are reported to extract diosgenin (Vendl et al. 2006; Niño et al. 2007; Zhang et al. 2007; Contreras-Pacheco et al. 2013; Yi et al. 2014; Padhan et al. 2020). Also, the analytical methods and tissue samples vary considerably between them, which makes it difficult to compare the levels of diosgenin. Therefore, the values published by these studies should be compared with caution. For these reasons, a uniform procedure for the preparation of samples and analysis of diosgenin is highly desirable, aiming to recover reliable information about the diosgenin content of various species and cultivars of of *Dioscorea* (Vendl et al. 2006).

11.4 Yam's Brief Phytochemistry

In addition to carbohydrates, essential amino acids, and vitamins, yams contain saponins and sapogenins, chemical compounds very similar to human sex hormones (Yi et al. 2014). Saponins are secondary metabolites of a glycosidic nature found naturally in edible and inedible plants that have several beneficial properties for human health and are widely used in the pharmaceutical industry (Raju and Mehta 2009). These substances are formed from a polar oligosaccharide linked to a water-insoluble nonpolar portion, generically called sapogenin. In saponins, normally the oligosaccharide is linked at the C-3 position of the sapogenin, but it can also be linked at the C-27 (in steroid saponins) or C-30 (in triterpenoid saponins) positions (Williams and Gong 2007; Raju and Mehta, 2009) (Fig. 11.1).

The nature of the oligosaccharide portion and sapogenin determine the physical, chemical, and biological properties of saponins (Rebelo 2011), which justifies the

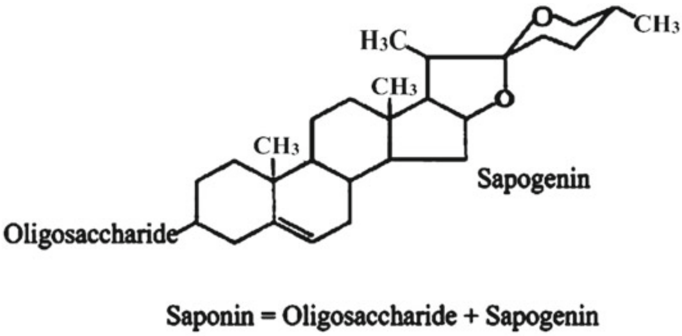


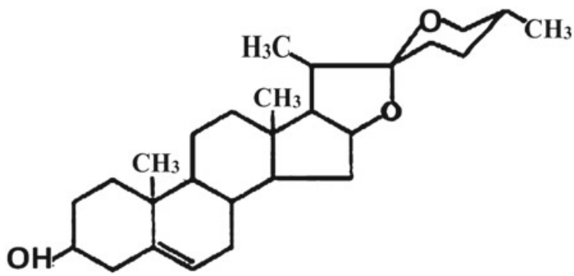
Fig. 11.1 General molecular structure of steroidal saponins

extensive variety of saponins existing in plants (Williams and Gong 2007). According to Guclu-Ustundag and Mazza (2007), saponins occur in at least 400 species of plants belonging to 60 different families. However, all the enzymes and genes involved in its biosynthesis are still unknown (Hua et al. 2017).

While diosgenin is a saponin formed by a steroidal sapogenin, with a glycosidic portion, found in several plant species, especially those of the genus *Dioscorea* (Dutta 2015), the diosgenin molecule is composed of a hydroxyl group at the C-3 position and a double bond at the C-5 position. It has six rings: A, B, C and D (cyclopentanophenanthrene system, standard on steroids), E (tetrahydrofuran), and F (tetrahydropyran). The E and F rings are fused at position C-22 to form a structure called a spiro (Fig. 11.2). These functional groups of bonds and rings are fundamental in the structural conversion of diosgenin and originate other pharmacologically active compounds (Quan et al. 2005).

As diosgenin is not metabolically synthesized by the human body, there has been an increasing demand for this substance from a plant origin in the pharmaceutical industry, which has been driven the introduction and cultivation of *Dioscorea* species in several countries. Among these, China and Mexico stand out, which together account for 67% of the world's diosgenin production (Li et al. 2010). Drugs produced from diosgenin have a turnover of more than US$ 40 billion annually in the global market, equivalent to about 10% of total medicines in the world (Long et al. 2019).

Fig. 11.2 General molecular structure of diosgenin



Currently, China is the leading international supplier of diosgenin and its derivatives, producing about 5000 tons annually (Jin et al. 2017).

On the other hand, the quantity and quality of diosgenin used in the pharmaceutical industry have not increased, mainly due to the decline in wild populations of *Dioscorea* caused by over-harvesting, the difficulty in obtaining new cultivars capable of providing satisfactory amounts of diosgenin and little exploitation of the diversity of the genetic resources (Coursey 1967; Singh et al. 2016).

11.5 Medicinal and Nutritional Properties of *Dioscorea* spp.

Several medicinal properties and pharmacological activities for diosgenin are reported in the literature, such as anti-inflammatory, antifungal, and hypoglycemic, which allows its use for cough relief, lower cholesterol, and stimulation of the liver bile secretory cell growth (Pan et al. 2013). A considerable amount of research was produced, highlighting impact/range in human health with the different *Dioscorea* spp. Ghosh et al. (2015) elaborated a complete phytochemistry review of *D. bulbifera* regarding their therapeutic importance, and Ikiriza et al. (2019) provided up-to-date information about its photochemistry, clinical benefits, conservation status, and best possible way on how this plant can be conserved for future use. These authors pointed out the medicinal uses of *D. bulbifera* such as contraceptives, sexual vigor remedy and treatment of piles, dysentery, syphilis, ulcers, tuberculosis, leprosy, cough, and diabetes. Also, Adeosun et al. (2016) described the efficacy of ethanolic extract of the peel of *D. bulbibera* as a chemotherapeutic. The authors affirmed that this species is a novel source of bioactive compounds but also ascertained its health-promoting qualities. In his pharmacological review, Subasini et al. (2013) indicated that the aerial tubers possess significant activities like purgative, deflatulent, aphrodisiac, rejuvenating and tonic, anthelmintic and is used in haematological disorders, scrofula, syphilis, haemorrhoids, flatulence, diarrhea, dysentery, worm infestations, general debility, diabetic disorders, polyuric, and skin disorders.

Many studies focus on the use of wild yam (*D. villosa*) to prevent menopause (Komesaroff et al. 2001; Hsu et al. 2008). Other problems related to women's quality of life have been the subject of studies due to the benefits of diosgenin, such as osteoporosis and premenstrual tension (Chiang et al. 2011). Das et al. (2014) listed a set of 55 species of *Dioscorea* with contraceptive and abortifacient effects, many of them present in Table 11.1.

Dutta (2015) highlighted the use of diosgenin in the treatment of syphilis and leprosy based on 16 species occurring in the state of Assam, India, which have been used as a source of food and to cure certain ailments such as cough, cold, stomach ache, leprosy, burns, fungal diseases, skin diseases, contraceptive, dysentery, arthritis, and rheumatism, and among these species, *D. alata*, *D. pentaphylla*, *D. bulbifera* and *D. villosa* showed the maximum medicinal properties. This traditional knowledge has been transmitted over generations by ethnic communities of the region. Kwon et al. (2003) highlighted the use of diosgenin in the treatment of diabetics and those

Table 11.1 List of diosgenin-contained *dioscorea* species, their origins, and respective diosgenin percentages, according to Martin (1969)

Species	Origin	Diosgenin (%)
D. abyssinica	Africa	Trace
D. alata	Philippines Islands	None or 0.25
D. althaeoides Knuth	China	Some
D. asclepiadea Prain & Burk	Japan	0.5
D. auriculata Poepp	Chile	0.2
D. balcanica Kosanin	Europe	2.0
D. bartlettii Morton	Mexico, Guatemala	0.8
D. belizensis Lundell	British Honduras	2.6
D. bulbifera	Africa, India	None or 0.5
D. capillaris Hemsl	Mexico	1.2
D. caucasica	Russia	0.6
D. cayenensis	Africa	None or 0.2
D. chiapensis Matuda	Guatemala	1.0
D. collettii	China	2.0
D. composita	Mexico	13.0
D. convolvulacea subsp. *grandifolia* (Schlecht.) Uline	Mexico	0.2
D. cyphocarpa Robinson	Mexico	0.2
D. deltoidea	India	8.0
D. dugesii Robinson	Mexico	0.2
D. escuintlensis Matuda	Guatemala	Some
D. esculenta	India	0.7
D. fastigiata Gay	Chile	Some
D. floribunda	Central America	10.0
D. floridana Bartlett	U.S.A	1.7
D. friedrichsthalii Knuth	Costa Rica	4.0
D. galeottiana Knuth	Mexico	Trace
D. glauca Muhl	North America	1.0
D. gracillima Miq	Japan	0.2
D. grandifolia (probably *D. galeottiana* Knuth)	Mexico	0.2
D. hirsuta Mart. & Gal. (probably *D convolvulacea* Chain. & Schlecht.)	Mexico	0.3
D. hirsuticaulis Rob. (probably *D jaliscana* F. Matuda)	Mexico	0.1
D. hispida Dennst	Philippine Islands	None or 0.73
D. izuensis Akahori	Japan	1.0
D. jaliscana Wats	Mexico	0.3

(continued)

Table 11.1 (continued)

Species	Origin	Diosgenin (%)
D. japonica	Japan	None or 1.0
D. laxiflora Mart	Brazil	None or some
D. lecardii De Wild	Uganda	1.0
D. lobata Uline	Mexico	0.5
D. malifolia Bak	South Africa	Trace
D. mexicana Scheidw	Mexico	0.4
D. militaris Robinson	Mexico	0.4
D. minima Rob. & Seaton	Mexico	0.3
D. minutiflora Engl	Africa, Uganda	None or trace
D. multiflora Mart. Ex Griseb	Argentina	1.0
D. multinervis Benth	Mexico	0.3
D. nelsonii Uline	Mexico	1.8
D. nervosa Phil	Chile	Some
D. nigrescens Phil	China	Some
D. nipponica	Japan	2.0
D. nummularia	India	Trace
D. orbiculata Hook	Malaya	Some
D. panthaica Prain & Burk	China	2.0
D. plumifera Rob	Mexico	0.4
D. polygonoides	Honduras	0.25
D. polystachya Turcz	Russia	0.6
D. prazeri Prain & Burk	India	2.1
D. prazeri var. *glauca*	India	4.5
D. preussii Pax	Tanzania, Uganda	None our 0.3
D. pringlei Rob	Mexico	0.4
D. pubera	India	–
D. quaternata J. F. Gmel	U.S.A	1.2
D. quinqueloba Thunb	Japan	0.4
D. remotiflora Knuth	Mexico	0.3
D. septemloba	Japan	0.1
D. sititoana Honda et Jotani	Japan	Trace
D. spiculiflora	Mexico	15.0
D. subtomentosa Miranda	Mexico	0.4
D. sylvatica	South Africa	6.0
D. tenuipes Franch & Sav	Japan	0.1

(continued)

Table 11.1 (continued)

Species	Origin	Diosgenin (%)
D. tepinapensis Uline (probably *D. composita*)	Mexico	0.7
D. testudinaria Knuth	South Africa	0.6
D. tokoro Makino	Japan	1.0
D. tomentosa	India	Trace
D. ulinei Greenm	Mexico	0.4
D. urceolata Uline	Mexico	0.5
D. villosa	U.S.A	1.3
D. wallichii Hook. F	India	Trace
D. zingiberensis	China	Some

with obesity problems from the use of *D. nipponica*. Sharma and Bastakoti (2009) identified the traditional utilization of nine species of *Dioscorea* in central Nepal and reported the use of diosgenin in the treatment of tuberculosis with *D. bulbifera* and stomach problems with *D. pentaphylla*.

Nabatanzi (2016) report on the consumption of yams (*D. cayenensis*, *D. minutiflora*, *D. odoratissima* Pax, *D. alata,* and *D. bulbifera*) in seropositive groups in Uganda. For the author, despite the already recognized medicinal properties of *Dioscorea* spp., these species need to be looked into more carefully for scientific validation of their nutrient quality and conservation measures toward their sustainable production. The South American *D. trifida* has shown reduced inflammatory parameters associated with food allergies and has the potential to prevent and treat this disease (Mollica et al. 2013).

The anticancer action of diosgenin, acting mainly by inhibiting the cell cycle and inducing apoptosis, was found among 14 *Dioscorea* species (*D. alata, D. belophylla*, *D. bulbifera, D. dumetorum, D. esculenta, D. hamiltonii, D. hirtiflora, D. hispida, D. kamoonensis, D. opposita, D. pentaphylla, D. pubera, D. wallichii, and D. spinosa* Wall. ex Hook. f.) (Kumar et al. 2017). An extensive review presented by Sethi et al. (2018) has compiled and analyzed the role of diosgenin in modulating various oncogenic transcription factors and intracellular molecular targets that drive tumor initiation, progression, and metastasis. The authors concluded that several challenges, such as developing novel delivery systems, pharmaceutical formulations, and semi-synthetic derivatives that are water-soluble, need to be overcome to uncover diosgenin's benefits either as a chemopreventive or therapeutic agent.

Dufie et al. (2013) underline that the low sodium but high potassium and total dietary fiber contents indicate the possible preventive role that *D. alata* could play in managing-related chronic diseases, which may be due to the action of diosgenin. Based on the nutritive evaluation studies on wild edible yams (*Dioscorea alata, D. bulbifera, D. esculenta, D. opposita, D. pentaphylla, D. spicata* Roth*, D. tomentosa* Koen ex Roxb., and *D. wallichii*) consumed by the Kanikkars tribals and Palliyars, India, it can be summarized that most of them were found to be a good source of protein, lipid, crude fiber, starch, vitamins, and minerals (Shajeela et al. 2011). In Koraput, India, wild yams make a significant contribution to the diets and economic welfare of tribal people. A study conducted by Padhan et al. (2020) carried out to evaluate the proximate, nutritional, and anti-nutritional compositions as well as the physic-functional properties in eight wild and one cultivated *Dioscorea* species. Results showed that the wild species, such as *D. opposita*, *D. hamiltonii,* and *D. pubera,* showed better nutritional composition than the other yam species, with significantly higher amounts of nutrient and mineral content. The study also suggested that these wild yam species are a safe food source for local consumption and domestication, leading to potential improvement of food security.

Childhood malnutrition is a current and perpetual public health concern in many African countries. Challenges remain for the difficulty in formulating nutritionally adequate diets. Leng et al. (2019) investigated the effect of *D. schimperiana* Kunth pulp color on nutritional composition and antioxidant activity of formulated yam-based complementary food. The authors found a positive correlation between the yam color and the contents in carbohydrates (0.64), total phenols (0.82), ß-criptoxanthine (0.6), zeaxanthin (0.86), and a significant correlation for antioxidant activity, such as alpha (1.00) and beta carotene (0.91) and total carotenoid provitamin A levels (0.94). In Brazil, Teixeira et al. (2013) highlighted the feasibility of purple yam (*D. trifida*) bread as a health-promoting food-based also in the nutritive evaluation profile. Beyerlein and Pereira (2018), in a morphological characterization of 20 *D. trifida* landraces from the Amazon in Brazil, found that pulp color was the main character dividing the accessions into two groups, one with white pulp tubers (seven accessions, but one of them had purple pulp color) and another with purple pulp tubers (13 accessions). Nascimento et al. (2015) also found high variability for pulp color among *D. trifida* accessions from the South, Southeast, Central-West, and North regions in Brazil, with the purple (13 accessions) and white-purple (18 accessions) tuber colors predominating in the Central-West and North regions. Therefore, further studies on the nutritional properties of purple pulp color of *D. trifida* tubers seem to be promising, since there is plenty of availability of this tuber color. Increasing provitamin A carotenoid intake through biofortification using some of the underutilized root tuber staples can reduce the prevalence of vitamin A deficiency among the vast consumers of yams (Ukom et al. 2014).

11.6 Perspectives

As the production and quality of diosgenin have decreased due to the lack of high-quality germplasm, the scarcity of information related to the region where species with a high content of diosgenin are found, as well as the decline of *Dioscorea* populations due to extensive harvesting, the identification of the new potential ecological distribution of diosgenin-contained *Dioscorea* species is required.

Little attention to research, minimal commercialization, and deficient political structures are the main obstacles to harnessing the real potential of *Dioscorea* spp. The most important compound of *Dioscorea* is diosgenin, currently used in the synthesis of steroid drugs; however, other potential uses of these compounds and related compounds need to be studied extensively to validate their quality and adapt their biological potentials.

An attempt should also be made to determine the mechanism of action, bioavailability, and physiological pathways of diosgenin and its derivatives for its possible applications in drug discovery and the cure of various diseases. Studies should also be carried out in order to use diosgenin to formulate new drugs to combat pathogens and microorganisms. Research on these species of *Dioscorea* will open new perspectives in the study of biodiversity management for sustainability, development, germplasm conservation, pharmacology, and many other new fields of research in plant and pharmaceutical science.

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