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Origin, cultivation and conservation of the food and medicinal culture of yams (*Dioscorea* spp.)

Origem, cultivo e conservação da cultura alimentar e medicinal dos carás (*Dioscorea* spp.)

Origen, cultivo y conservación de la cultura alimentaria y medicinal de los ñames (*Dioscorea* spp.)

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Abstract

Unconventional Food Plants (UNFP) is a name given to plants or forms of consumption of a species that are unusual for most of the population. Yams (*Dioscorea*) are among the neglected plants. This review aims to broaden understanding of this genus in terms of botany, phytotechnology, phytochemistry, conservation, and food and medicinal use. The Dioscorea genus has 650 species, particularly in seasonal tropical regions, and commonly has tubers rich in starch, a source of energy, and secondary metabolites. This is one of the most diverse genera in the country, present in all states and all biomes, especially in the transition to open forest formations. In São Paulo State, there are 48 native species of the genus (seven endemic to the state and 24 endemic to Brazil). The extraction and cultivation of medicinal yams (barbascos) needs to be better studied in Brazil.

Keywords: Food culture, Unconventional Food Plant, Agrobiodiversity, Genetic conservation.

Resumo

Plantas Alimentícias Não Convencionais (PANC) é uma denominação dada às plantas ou formas de consumo de uma espécie incomuns para a maioria da população. Os carás (*Dioscorea*) estão entre as plantas negligenciadas. Essa revisão visa ampliar o entendimento sobre esse gênero em termos botânicos, fitotécnicos, fitoquímicos, de conservação e do uso na alimentação e medicinal. O gênero *Dioscorea* tem 650 espécies, particularmente em regiões tropicais sazonais, sendo comum apresentarem tubérculos ricos em amido, fonte de energia, e em metabólitos secundários. Este é um dos gêneros com maior diversidade no país, presente em todos os estados e em todos os biomas, especialmente na transição para formações florestais abertas. No estado de São Paulo, ocorrem 48 espécies nativas do gênero (sete endêmicas do estado e 24 endêmicas do Brasil). A extração e o cultivo de carás medicinais (barbascos) precisa ser melhor estudado no Brasil.

Palavras-chave: Cultura alimentar, Planta Alimentícia Não Convencional, Agrobiodiversidade, Conservação genética.

Resumen

Las plantas alimenticias no convencionales (UNFP) son plantas o especies que no son comúnmente consumidas por la mayoría de la población. El ñame (*Dioscorea*) se encuentra entre estas plantas olvidadas. Esta revisión busca ampliar la comprensión de este género en términos de botánica, fitotecnia, fitoquímica, conservación y su uso en alimentos y medicina. El género *Dioscorea* cuenta con 650 especies, particularmente en regiones tropicales estacionales, y comúnmente presenta tubérculos ricos en almidón, una fuente de energía, y metabolitos secundarios. Este es uno de los géneros más diversos del país, presente en todos los estados y biomas, especialmente en la transición a formaciones forestales abiertas. En el estado de São Paulo, se encuentran 48 especies nativas del género (7 endémicas del estado y 24 endémicas de Brasil). La extracción y el cultivo de ñame medicinal (barbascos) requieren mayor estudio en Brasil.

Palabras-clave: Cultura alimentaria, Planta Alimenticia No Convencional, Agrobiodiversidad, Conservación genética.

INTRODUCTION

Throughout human history, more than 7,000 plant species have been used as food, although 30,000 are recognized as having potential for food use. However, only 150 species are commercially cultivated, with only four (rice – *Oryza sativa* L., wheat – *Triticum* spp., corn – *Zea mays* L., and potato – *Solanum tuberosum* L.) accounting for 60% of the energy supply (Padulosi et al., 2013).

Neglected crops, underutilized plants, traditional crops, and Unconventional Food Plants (UNFP) are names given to species or forms of consumption of a given species that are uncommon to most of the population and are not normally included in official statistics. Many of these species were more widely used in the past, hence the association with the terms “traditional” and “underutilized.” They are often neglected because they are not widely consumed, despite their high nutritional value and relative ease of cultivation or exploitation (Padulosi et al., 2013; Kinupp; Lorenzi, 2014; Baldermann et al., 2016).

Yams (*Dioscorea* spp.) are among the neglected plants or UNFP (Hernández Bermejo; León, 1994; Padulosi et al., 2013; Kinupp; Lorenzi, 2014). *Dioscorea alata* L. (water yam, purple yam, greater yam or yam) is the most widespread in Paraná and São Paulo, in addition to being cultivated in Rio de Janeiro, Minas Gerais, Mato Grosso, and the Northeast and North regions, being the least common in the Brazilian Northeast, where *D. cayennensis* Lam. (white yam, yellow yam, West African yam, Guinea yam or yam) is the most widely cultivated (Peressin; Feltran, 2014; Couto; Fraga, 2020).

There is considerable confusion in the use of the terms “carás” and “inhames” (yams) for species of *Dioscorea* (Dioscoreaceae) or Araceae - *Colocasia esculenta* (L.) Schott. In Brazil, the term “carás,” of indigenous origin, was associated with *Dioscorea* species (Corrêa, 1926). Although the Ministry of Agriculture, Livestock, and Supply (MAPA, 2010) recommended the terms “inhame” for *Dioscorea* and taro for *Araceae* (IPGRI, 1999), the records of cultivars under the name “inhame” (associated or not with taro) correspond to Araceae, and there are still no records of edible species of *Dioscorea* (MAPA, n.d.). In official statistics (São Paulo, 2009; IBGE, 2019), the terms “cará” and “inhame” are used distinctly, and the term taro is not used. Although not explicit, there are indications that “cará” applies to *Dioscorea*, while “inhame” applies to Araceae.

"Caratinga" is another popular name often associated with native *Dioscorea* species (IBGE, 1980; Rios; Pastore Jr., 2011), while barbasco is the popular name given to medicinal species of *Dioscorea* in Mexico (De Teresa, 1999; Laveaga, 2005) and used in Brazil (Zullo et al., 1987). Although not as widespread for *Dioscorea* species, the term barbasco is commonly used in Brazil and is associated with plants for medicinal use, such as *Buddleja stachyoides* Cham. & Schltdl., *Verbascum virgatum* Stockes, and *Pterocaulon virgatum* (L.) DC. (Moreira; Bragança, 2011). Therefore, in this article, we refer to different edible species of the genus *Dioscorea* as yams and medicinal species as barbascos.

The objective of this article is to present an updated review of the cultivation and consumption potential of different *Dioscorea* species, covering aspects of botany, cultivation, producing regions, and food or medicinal uses, with a view to enhancing and promoting food and nutritional security around such a neglected plant genus.

METHODOLOGY

A literature review on Dioscorea was conducted by accessing original or review articles, books, monographs, dissertations or theses, and other types of technical and scientific publications in Portuguese, Spanish, French, and English. Works were accessed using the descriptors "*Dioscorea*", "cará", "yam", "diversity", "cultivation", "agroforestry", "family farming", "management", "fertilization", "agroecology", among other topics and their equivalents in the languages consulted, in the Google Scholar, Scielo, Rede speciesLink, Rede Reflora, and other databases, in order to contribute to the characterization of *Dioscorea* in the world, its origin, cultivation, and nutrition.

RESULTS AND DISCUSSION

Origin and characteristics

The genus *Dioscorea* Plum. ex L. was established in 1753 and named in honor of Pedanios Dioscorides (40-80 AD), considered the leading authority on drugs from the 1st to the 18th century, and an expert on mild laxatives and strong purgatives, analgesics for headaches, antiseptics, emetics, chemotherapeutic agents, and contraceptives (Pedralli et

al., 2004; Riddle, 2011), pharmacological properties that some species of the genus possess.

Dioscorea is a widely dispersed genus that can be found in tropical, subtropical, and temperate regions (Montaldo, 1991; Pedralli et al., 2002; Siqueira, 2009). Consisting of climbing, dioecious or monoecious, voluble, geophytic species with tubers or rhizomes (Figure 1) containing starch and steroidal saponins, it is the largest genus of Dioscoreaceae (more than 90% of species) with a predominantly tropical distribution, with maximum diversity, in line with the presence of pronounced storage organs, is found in seasonal (monsoon) climates (Purseglove, 1972; Cronquist, 1981; Huber, 1998; Kirizawa et al., 2016; Stevens, 2017).

The Dioscoreaceae family was first recognized by Brown in 1819 under the name Dioscoreae. In terms of the distribution and knowledge of the species, there are approximately eight genera, with about 850 species, 95% of which belong to the genus *Dioscorea* (Coursey, 1967; Mabberley, 2008; Castro et al., 2012). Couto et al. (2018) report 650 species, commonly with starch-rich tubers, useful as a source of energy and often containing secondary metabolites.

In Dioscoreaceae, chromosomes tend to be small and numerous, with numbers ranging from n = 6 to 72, with a high frequency of polyploidy, especially tetraploids, and variable ploidy within a single species, as in the case of *D. alata* L. and other cultivated species (Purseglove, 1972; Huber, 1998; Viruel et al., 2019). The $\delta^{13}C$ values of several studied species of *Dioscorea* ranged from –25.4 to –30.1‰, corresponding to the C3 photosynthetic type (Cornet et al., 2007).

Figure 1 – Underground tubers (A – access SRT 97, and C – access SRT 108) of the yam (*Dioscorea alata*), barbasco (D, *D. floribunda*) and aerial tubers of the yam (B) and air potato (E-F, gizzard yam access, *D. bulbifera*).
Source: Authors, 2025.

According to Lebot (2009), the genus *Dioscorea* was widely dispersed throughout the world at the end of the Cretaceous period, evolving in both the New and Old Worlds. This led to the emergence of distinct species in the Americas, Africa Continent, Madagascar, South and Southeast Asia, Australia, and Melanesia. Couto et al. (2018) indicate four origins of *Dioscorea* in the Neotropics, with two more diverse lineages originating between the Eocene and Oligocene (approximately between 35 and 23 million years ago), respectively, in the southern Andes and in a large and disconnected group of areas, including Central America, the northern Andes, and the Atlantic Forest. Both lineages occupied the "dry diagonal" of South America after the Miocene (23 and 5.3 million years ago), but the New World II clade became associated with forest habitats. Several exchanges occurred between the dry diagonal and the adjacent forest biomes, with

dispersals to Central America occurring before the closure of the Isthmus of Panama and the dispersal of *D. antaly* Jum. & H.Perrier to Madagascar (Couto et al., 2018).

The Neotropical region is home to the greatest diversity of edible yam species, with South America having varieties of Dioscorea possibly brought by the Portuguese in the 16th century. Vavilov (1951) considers that the species *D. alata* and *D. esculenta* (Lour.) Burkill originated in Burma and Assam, locations in India. Chevalier (1946) points to the African origin of the species *D. cayennensis*.

By 2010, *Dioscorea* germplasm collections totaled 15,903 accessions conserved *in situ*, with the remainder distributed among more than 98 institutions around the world, especially in India, Vietnam, the Philippines, France, and the Pacific Islands (FAO, 2010). The International Institute of Tropical Agriculture (IITA) was the largest curator, with about 21% of all accessions registered worldwide, highlighting a 57% increase in the number of *Dioscorea* accessions registered in the collection, which covers the species: *D. cayennensis* subsp. *rotundata* (Poir.) J.Miège (68%), *D. alata* (21%), *D. burkilliana* J.Miège (6%), *D. abyssinica* Hochst. ex Kunth (1.6%), *D. cayennensis* subsp. *cayennensis* (1.5%), D. *dumetorum* (Kunth) Pax (1.3%), *D. bulbifera* L. (1.2%), *D. esculenta* (0.4%), *D. preussii* Pax (0.17%), and *D. mangenotiana* J.Miége (0.14%) (Darkwa et al., 2020), with most of the accessions maintained in the form of tissue cultures (IITA, 2018).

In 2010, a group of experts prepared a global strategy for the *ex situ* conservation of yams, given the need to increase the representativeness of *Dioscorea* collections from the Americas and Asia. In 2021, the global strategy was revised with a proposal to create a network of *ex situ* collections dedicated to preserving the maximum diversity of edible *Dioscorea* species, to which Embrapa is a signatory (Genesys, 2024).

Diversity and conservation of yams at São Paulo State

Dioscorea is one of the most diverse genera in Brazil, ranking among the 30 genera with the highest number of species (130-140, of which 94-104 are endemic) in the country. It occurs in all states and biomes, especially on the edge of tree formations and in the

transition to open formations, with naturalized (*D. bulbifera*) or cultivated (*D. alata* and *D. cayennensis*) species (Forzza et al., 2010; Couto; Fraga, 2020).

In the Germplasm Collection of the Campinas Agronomic Institute (IAC), of the São Paulo Agency for Agribusiness Technology (APTA), there are 24 accessions of *D. alata* and one or more accessions of *D. bulbifera*, *D. composita* Hemsl. and *D. floribunda* M.Martens & Galeotti, and some recent new introductions. The IAC Herbarium collection contains 60 samples of 22 *Dioscorea* species (43 samples of 17 species collected in the State of São Paulo), referred to as native or cultivated in the State (IAC, 2025).

In an evaluation of *Dioscorea* accessions, only 68 discriminating descriptors were obtained among 97 descriptors evaluated (Perini et al., 2021). To improve the morphoagronomic characterization and distinction of *Dioscorea* accessions, based on the internationally defined key descriptors for this group of plants (Bioversity International/IITA, 2009), new criteria adapted from the International Plant Genetic Resources Institute/International Institute of Tropical Agriculture (IPGRI/IITA, 1997) should be evaluated, which are: presence of aerial tubers (1-present, 2-absent); presence of roots in tubers (1-present, 2-absent); shape of tubers (1-elongated, 2-oval, 3-irregular); color of tuber pulp (1-white, 2-yellow, 3-purple, 4-purple with white) and presence of slime after cutting the tubers (3-little, 5-intermediate, 7-a lot). Aspects such as cooking time, flavor, texture, and color after cooking should also be evaluated.

At São Paulo State, there are 48 native species of the genus *Dioscorea* (seven endemic to the state and another 24 endemic to Brazil), in addition to *D. bulbifera* (air potato, air yam, bitter yam, potato yam, yam), which is naturalized, and *D. alata*, which is cultivated (Couto; Fraga, 2020). Among the native species of São Paulo State are two: *D. altissima* Lam. and *D. dodecaneura* Vell., among the three species exploited for food consumption (Couto; Fraga, 2020). However, there are indications of cultivation in São Paulo of another native Brazilian food species (*D. trifida* L.f.) (Nascimento et al., 2015), as well as the exotic *D. cayennensis* (Bressan et al., 2014). *Dioscorea trifida* is native to Minas Gerais, the Midwest, and the North, as well as some states in the Northeast (Maranhão, Paraiba, and Pernambuco) (Couto; Fraga, 2020). In addition to these, there are records of

the native occurrence of nine other species in São Paulo. In other words, despite the potentially available biodiversity, native and even cultivated species of *Dioscorea* are still poorly known, even in São Paulo State, where there are large universities and research centers.

Despite the importance of *Dioscorea* raw material for medicinal purposes, only two species (*D. composita* and *D. floribunda*) have been studied for diosgenin concentration among the accessions in the IAC Germplasm Collection, with levels of 3.15 ± 1.41% and 4.72 ± 0.24% in the respective dry matter of the tubers (Zullo et al., 1987). In *D. composita*, the diosgenin content increases with the age of the plant, reaching a pronounced maximum around the third year of cultivation and stabilizing around the sixth year (Zullo et al., 1987). With the exception of the native *D. olfersiana* Klotzsch ex Griseb. (Haraguchi et al., 1994), *D. trifida* (Mollica et al., 2013), and *D. delicata* R.Knuth (Kirizawa et al., 2016), among the species occurring in São Paulo, data are only available for the exotic species *D. alata* and *D. bulbifera* (Peng et al., 2011; Sheikh et al., 2013; Wong et al., 2015; Price et al., 2016; Wu et al., 2016; Ikiriza et al., 2019).

Considering the data from the speciesLink Network and the Reflora Network, and excluding repetitions, duplicates, and materials cultivated in institutions (IAC, ESALQ, etc.), no specimens were found for seven of the São Paulo species of *Dioscorea*: *D. cinnamomifolia* Hook., *D. kunthiana* Uline ex R.Knuth, *D. lundii* Uline ex R.Knuth, *D. planistipulosa* Uline ex R.Knuth, *D. secunda* R.Knuth, *D. grisebachii* Kunth, *D. polystachya* Turcz. (Couto; Fraga, 2020), and there is no indication of state and municipality in the databases for another species: *D. itapirensis* R.Knuth, however indicated as having been collected in Itapira (SP) (Knuth, 1917).

On the other hand, 11 species are not indicated as occurring in São Paulo State, two of which are not indicated as occurring in Brazil - *D. gracilis* Hook. ex Poepp. and *D. ×monandra* Hauman (Couto; Fraga, 2020), have records in herbaria for the state and require verification of identification and/or occurrence: *D. acanthogene* Rusby (AC to TO and BA and from there to MG and MS), *D. asperula* Pedralli and *D. deflexa* Griseb. (MG, GO, and DF), *D. furcata* Griseb. (RJ and PR to RS), *D. loefgrenii* R.Knuth (reported in São Paulo State, but indicated as from Minas Gerais in the observations), *D.*

mantiqueirensis R.Knuth (ES), *D. martiana* Griseb. (CE to PE, MT, RJ, and PR), *D. orthogoneura* Uline ex Hochr. (MS and GO to MA- and from there to BA *and* MG) and *D. pseudomacrocapsa* G.M.Barroso, E.F.Guim. & Sucre (RJ). In total, there are 53 species recorded (excluding synonyms and spelling errors) with data available on the Networks.

Yams and food, nutritional, and medicinal security

In 2022, the Food and Agriculture Organization of the United Nations (FAO) recorded an increase of 122 million people suffering from hunger worldwide compared to 2019, before the COVID-19 pandemic. In Africa, the continent with the largest share (98%) of global *Dioscorea* production (75 Mt) (CIRAD, 2023), one in five people suffer from hunger, more than double the global average. In Brazil and many other countries where food inflation is high, this also contributes to worsening food insecurity among vulnerable populations (Baccarin et al., 2022).

Looking at the situation of hunger and the high growth in the consumption of ultra-processed foods, one wonders: why are the potential benefits of natural and healthy foods not valued in Brazil?

Yams are classified as an energy food source for consumers due to its high starch content, which reaches 80% by dry weight (Peroni, 2003; Zhu, 2015; Freire; Meira, 2023). The high ratio of amylose to amylopectin results in the functional properties and characteristics of starch, such as crystallinity and digestibility (Obidiegwu et al., 2020).

Yams are the staple food for more than 100 million people, predominantly in Africa (Price et al., 2016). In Benin, per capita production was 155 kg.inhabitant^{-1}.year^{-1}, and in Nigeria, 105 kg.inhabitant^{-1}year^{-1}. Africa accounts for 98.1% of global *Dioscorea* production, with 96% of this total being produced in East Tropical Africa and the Gulf of Guinea countries (FAO, 2024). In the Americas, in addition to the main species, *D. bulbifera* and three native species (*D. altissima*, *D. dodecaneura* and, mainly, *D. trifida*) have been cultivated on a larger scale or extracted for consumption, while in other parts of the world, four to seven other species of the genus are the most cultivated, and more than 50 are extracted as food (Purseglove, 1972; Kinupp; Lorenzi, 2014; Price et al., 2016).

Brazil ranks 12th among yam producers (out of a total of 57), with a production of 225,000 tons on 25,000 hectares of cultivated area (Oliveira et al., 2005). This represents second place in South American yam production, which corresponds to only 0.3% of global production, placing Brazil 42nd in production in relation to population size and 48th in relation to cultivated land area (FAO, 2024).

Yam cultivation has significant economic and social importance in the Northeast region, especially in the States of Paraíba and Pernambuco (Zona da Mata), as a food source and a vital part of the regional economy (Silva et al., 2024). Although neglected, yams generally have higher prices than other roots and tubers and are therefore considered a food for the more affluent classes, notably in the Northeast (personal observation).

For the population of Amazonas, yams are a low-cost food with high nutritional quality (Rocha et al., 2020). In Amazonas, *D. trifida* is a staple food, consumed at breakfast, with meals, or as flour used in the preparation of breads and cakes. *Dioscorea cayennensis* is an important crop in the regional economy of the Guaporé Valley in Rondônia, which has about 2,000 hectares under cultivation (Ressutti, 2021). Family farmers in the municipality of Caapiranga (AM) account for about 50% of the state's production of purple-fleshed yams (*D. trifida*), which have a high concentration of anthocyanins and antioxidant properties and are preferred by the population (Castro et al., 2012). Given the importance of this crop for the municipality, the Cará Festival was included in the Official Calendar of Events of the State of Amazonas, on September 5 and 6 (State Law 6.703/2024). Thus, *Dioscorea* has been officially celebrated for being rooted in the cultural heritage passed down from generation to generation since 2006 (Santos; Melo, 2021).

Traditionally, yams are consumed in various ways, depending on the region of Brazil. In the Northeast, yams are served boiled with butter; in Santa Catarina, they are used in the production of bread and biscuits or eaten boiled for breakfast, or, most commonly, as an alternative to potatoes (Siqueira et al., 2014). In the Southeast, *D. alata* is cultivated on a small and medium scale, with family farming focusing on self-consumption and the sale of surpluses. However, there has been a notable expansion in trade in the southern region

of Minas Gerais, where yams have become one of the ten most representative UNFP in terms of cultivated area (Silva et al., 2022).

Yams are a food that is beneficial to well-being and health, reducing the risk of disease due to its functional food characteristics (Monte-Guedes et al., 2019). Its consumption should be encouraged to overcome the barriers of regionalism (Noronha, 2014). Perhaps the lack of knowledge about the preparation methods and nutritional value of this important food is one of the reasons for the slow growth in its consumption and planted area in Brazil, unlike in the Amazon region. This was the case for a long time with sweet potatoes, *Ipomoea batatas* (L.) Lam., which are now so popular and widely consumed, unlike 30 years ago. With the spread of vegan and/or natural diets, interest in yams has grown with their use in various dishes and recipes (Oliveira, 2024).

Dioscorea bulbifera (air yam) can contribute to food security because it is widely distributed in Brazil in small-scale crops, mainly by family farmers (Gentil et al., 2023).

As food, yams are rich in several B vitamins (thiamine, riboflavin, niacin), as well as vitamins A, vitamin C (ascorbic acid), and carbohydrates (99.59%), mainly starch, which is the main energy reserve of vegetables and the main source of carbohydrates in the human diet, as well as appreciable levels of protein (0.09%) and fat (0.10%) (Peroni, 2003; Oliveira et al., 2007; Castro et al., 2012). In terms of nutritional properties, yams are superior to potatoes and cassava (*Manihot esculenta* Crantz.) (Dias et al., 2020).

Yams can contribute to combating food insecurity among populations in hard-to-reach places by processing them into flour, which increases the product's storage time. Yam flour can be used in the production of soups, breads, cakes, and snacks (Alves; Grossmann, 2002; Siqueira et al., 2014). The flour from the peel and pulp of *D. bulbifera* has good potential for use in baking, with significant levels of total protein and carbohydrates (11.97 ± 1.35 and 12.30 ± 1.69 g.100 g^{-1}) and starch (57.77 ± 3.73 and 75.70 ± 2.92 g.100 g^{-1}), respectively, and high levels of phenolic content in the peel (806.62 mg ± 6.72 mg of gallic acid Eq.100 g^{-1}) (Carneiro et al., 2020). Combining yam flour with rice flour makes it possible to produce pasta rich in hypoallergenic proteins and with good acceptability, after sensory analysis, similar to wheat pasta, which may meet

the emerging consumer demand for healthy products. Some yam varieties are still used as forage plants due to their high productivity.

Due to their chemical properties, *Dioscorea* tubers are classified as functional (Chiu et al., 2012; Chandrasekara; Kumar, 2016), as a rich source of starch, phytosterols, alkaloids, vitamin C (ascorbic acid), beta-carotene (provitamin A), B vitamins (thiamine – B1, riboflavin – B2, and niacin – B3), proteins (including the amino acids lysine and leucine), fats, fiber, calcium, cobalt, copper, chromium, tin, sulfur, iron, phosphorus, magnesium, manganese, niacin, potassium, selenium, silicon, sodium, and zinc (Brock; Autret, 1952; Purseglove, 1972; Sheikh et al., 2013; Peressin; Feltran, 2014; Dutta, 2015; Wu et al., 2016; Adepoju et al., 2017).

Certain species of *Dioscorea* play an important role in traditional medicine, being used in the treatment of various diseases (Sheikh et al., 2013; Kumar et al., 2017). However, antinutritional compounds, such as calcium oxalate, need to be identified and studied to support the expansion of yam use, given the nutritional, medicinal, and economic value that the crop has in certain regions (Padhan; Panda, 2020).

Dioscorea species are part of the European pharmacopoeia (Hernández Bermejo; León, 1994) and are rich sources of steroidal sapogenins, including diosgenin (Zullo et al., 1987). Diosgenin is one of the most important pharmaceutical raw materials for steroid drugs (such as corticosteroids, progestogens, and anabolic steroids) (Shen et al., 2018), with increasing reports on its pharmacological functions (Raju; Rao, 2012; Deshpande; Bhalsing, 2014). There is greater richness and diversity of species among medicinal *Dioscorea* than among edible ones. Diosgenin has been found in 137 different species of *Dioscorea*, with 41 of them having a concentration greater than 1%, which is of great value for use (Shen et al., 2018).

However, few native Brazilian species have been investigated for diosgenin, among them *D. laxiflora* Mart. ex Griseb. and *D. olfersiana* Klotzsch ex Griseb. (Haraguchi et al., 1994). Even for exotic species of yam, there is no cultivation in Brazil, despite our native *Dioscorea* biodiversity being a strong indicator of the possibilities for collection and cultivation in our country (Souza et al., 2024). In Mexico, between 1943 and 1975, first

the black yam (*D. mexicana* Scheidw.) and then barbasco (*D. composita*), and to a lesser extent yellow barbasco (*D. floribunda*), about 1.5 million kilograms of fresh tubers were extracted in 32 years of exploitation in tropical rainforests. Despite the wealth generated by the exploitation of barbasco for the extraction of diosgenin, few benefits were left for the collectors, but it brought academia closer to industry and contributed to the development of disciplines such as chemistry, botany, tropical ecology, and ethnobotany (Peña, 2023).

In folk medicine, *D. alata* and *D. bulbifera*, among others, are traditionally used against a number of ailments, with scientific indications of their healing potential and proven results in relation to allergies, hyperglycemia, osteoporosis, and other diseases (Pereira et al., 2002; Peng et al., 2011; Mollica et al., 2013; Sheikh et al., 2013; Hung et al., 2014; Rego et al., 2014; Dutta, 2015; Wong et al., 2015; Price et al., 2016; Wu et al., 2016; Ikiriza et al., 2019).

Aspects of agroecological cultivation of yams

Dioscorea plants are hardy and highly resistant to pests and diseases, adapting to almost all tropical and subtropical regions (Castro et al., 2012). Preference should be given to regions with a well-defined dry season of two to five months, annual rainfall of 1,500 mm, and an average temperature during the growing season in the range of 30 °C. Light, deep soils, rich in organic matter and with good moisture retention capacity, not subject to waterlogging, are the most suitable, because clay soils impair tuber development (Peressin; Feltran, 2014).

To plant Dioscorea, 3 to 5 $t.ha^{-1}$ of medium-sized seed tubers weighing 60 to 150 g are required. In the case of large tubers, they can be cut crosswise in half and stored in a ventilated place for healing, and then planted from June to October (Peressin; Feltran, 2014). Seed tuber management should avoid the introduction of pests and diseases into the cultivation area. In the Coastal Tablelands of the Northeast, high relative humidity and frequent rainfall, with maximum and minimum temperatures around 30 °C and 21 °C, respectively, were favorable conditions for the burning of cará leaves, also known as

black spot, the etiological agent being *Curvularia eragrostidis* (Henn.) Meyer, spread by wind, crop residues, and contaminated seed tubers, making it the most severe leaf disease in cultivation areas (Noronha, 2014). In the Recôncavo Baiano region, the widespread dissemination of phytonematodes in contaminated seed tubers has become a bottleneck for the sustainability of yam production (Santana, 2003; Castro et al., 2012).

Considering that the main diseases in *Dioscorea* are transmitted and spread through contaminated seed tubers (Noronha, 2014), agroecological management shows that immersing seed tubers in manioc juice for a period of 6 hours (60% manioc juice) (Carmo, 2009) to 9 hours (25%) (Lima et al., 2020) can induce 100% mortality of the nematode Scutellonema bradys (Steiner & LeHew) Andrássy, which causes the disease 'black skin of the cará' (Carmo, 2009; Lima et al., 2020). Neem extract (*Azadirachta indica* A.Juss) (2%) is another effective treatment for seed tubers (Barbosa et al., 2010). The application of palm sap to the aerial parts of the plants was also effective in controlling leaf blight, increasing the average weight of the tubers (Almeida et al., 2013).

For soil control, the use of antagonistic plants, such as brown hemp (*Crotalaria juncea* L.), cultivated for approximately two years, either alone or in association with pigeon pea (*Cajanus cajan* (L.) Huth), between rows of yams, was effective in reducing infestation by the phytoparasitic nematodes *S. bradys* and *Rotylenchulus reniformis* Linford & Oliveira in *Dioscorea* cultivation areas (Garrido et al., 2008).

As it is a climbing species with a herbaceous stem, the growth orientation of the *Dioscorea* plant favors its vegetative development, which can be achieved using a simple stake or trellis. In the Cuiabá Lowlands (MT), the use of stakes is preferred for more demanding varieties, as observed with *D. trifida* (Castro et al., 2012). By placing a 1.50 m long bamboo stick next to the plant at the time of planting or emergence, the plants themselves lean against and wrap around the stake, preventing the aerial part from contacting the soil (Carvalho et al., 2014; Oliveira et al., 2015).

In the São Paulo Plateau and Northwestern São Paulo State, crops are usually grown in monoculture and without staking, and sprinkler irrigation is used, although the plant does

well in hot regions with good rainfall and humidity, such as in the Ribeira Valley and Paraíba Valley in the State of São Paulo (Peressin; Feltran, 2014).

However, in most parts of the world, *Dioscorea* is still cultivated using shifting cultivation, after cutting and burning forest vegetation (CIRAD, 2023). This system, called fallow, stump clearing, or slash-and-burn, is an ancient tradition of most indigenous populations and has been assimilated by the remaining populations of colonization processes (Adams, 2000; Ferreira et al., 2020; Souza et al., 2024). The system begins with the clearing and burning of the forest for cultivation for a period that can vary from 1 to 3 years, followed by another fallow period to allow the soil fertility to return to the conditions prior to the establishment of the farm, which ensures the sustainability of the system for a variable period ranging from 5 (Ferreira et al., 2024) to 30 years (Neves et al., 2012).

Experts defend the concept of cultural forests, in which much of the biological diversity of today's tropical forests has evolved over thousands of years in conjunction with this type of human activity (Neves et al., 2012). These systems conserve a wide diversity of *Dioscorea* in different regions of Brazil (Castro et al., 2012; Ferreira et al., 2020; Souza et al., 2024). The creation of community banks of local *Dioscorea* varieties would be essential to improve *in situ*/on-farm conservation and for studies of genetic diversity and evolution (Castro et al., 2012). The management practices and exchange of materials among traditional farmers in the Ribeira Valley (SP) emphasize the important role they have played in the *in situ* conservation of *D. alata* (Bressan et al., 2011).

In Brazil, it is common to find a wide variety of *Dioscorea* in small fields, rather than a single species (Nascimento et al., 2015; Ferreira et al., 2020; Souza et al., 2024). Consortiums with a diversity of plants and traditional crops of other tubers, such as cassava and sweet potatoes (Ferreira *et al.*, 2020), play a fundamental role in the conservation of Dioscorea ethnovarieties and in promoting food and nutritional security for families (Souza *et al.*, 2024). Agroforestry backyards are present in several regions, such as in Sinop (MT), where Indian yam (*D. trifida*) and yam (*D. cavennensis*) occur (Rondon; Hoogerheide, 2020); in Santa Catarina, around Babitonga Bay, where native and exotic yams are cultivated in fields and on anthropogenic soils, in monoculture or in

consortium with corn or yams (Souza *et al.*, 2024); or in areas in the south of the state of São Paulo (SP), where different creole varieties of *D. alata* are cultivated using the slash-and-burn system by traditional farmers who use the yams for their own consumption, and some families also cultivate them for local markets, following the same model of subsistence agriculture, characterized by low energy consumption and intensive family labor (Bressan *et al.*, 2011).

The Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) has sought to operate in Africa, Asia, and Latin America, proposing systems that improve soil fertility with fallow techniques, sequential cultivation (rotation), crop consortiums, service plant management, and agroforestry. In addition, it seeks to promote the use of varietal diversity and the dissemination of selected genotypes of Dioscorea sp. (CIRAD, 2023).

Agroecological systems for growing yams should seek to conserve the soil, combining the use of cover crops, green manure, mulch (Eruola *et al.*, 2012), or plastic mulching (Carvalho *et al.*, 2014). The use of grass mulch reduced the maximum soil temperature by up to 2 °C at a depth of 15 cm during the critical thermal period (January to March), leading to greater emergence and productivity of tubers of *D. cayennensis* subsp. *rotundata* tubers of 4-6 tons.ha^{-1}.crop^{-1} greater than polyethylene mulching or no mulch (Eruola *et al.*, 2012).

In the No-Till Farming System (NTFS), as evaluated for cassava cultivation, the cover crops selected for the system with yams should recycle the nutrients required by the yams and provide enough residues to keep the soil covered in order to reduce the need for weeding and irrigation (Devide *et al.*, 2019). In the SPD, soil preparation should be reduced and localized in the row or planting bed, with a minimum time interval between cover crop management and yam planting, leaving the residues mowed as cover on the ground.

Caras are adept at taking advantage of the residual effect of fertilizers applied to previous crops (Peressin; Feltran, 2014). Fertilization for yams requires the addition of organic matter and limestone to raise base saturation to 80%. According to soil analysis, 20

kg.ha^{-1} of N, 50 to 100 kg.ha^{-1} of P_2O_5, and 40 to 100 kg.ha^{-1} of K_2O should be applied at planting (Oliveira *et al.*, 2011). The incorporation of organic matter prior to planting also helps to reduce the population of phytoparasitic nematodes (Santos *et al.*, 2009).

Yams plants respond variably to shading. *Dioscorea esculenta*, for example, showed moderate tolerance to 75% shading (Johnston; Onwueme, 1998), while *D. alata* showed differentiation at light intensities of 42, 72, and 102 µmol.m-2.s-1, which did not occur only at 12 µmol.m-2.s-1 (John *et al.*, 1993). In Agroforestry System (AFS) cultivation, land use integrates perennial woody species and agricultural crops and/or livestock in spatial and temporal arrangements, obtaining economic and ecological benefits (Schroth *et al.*, 2004; Batish *et al.*, 2008; Umrani; Jain, 2010; Bernacci *et al.*, 2021). There is a wide variety of combinations and possibilities for SAFs (Bernacci *et al.*, 2021), with biodiversity consisting of both planned and unplanned components that interact to optimize ecological processes with environmental and socioeconomic benefits (Schroth *et al.*, 2004).

Dioscorea is present in agroforestry backyards or homegardens in Brazil and around the world, in systems that have evolved through the hands of farmers, are managed around homes, and conserve a wide diversity of yams for food and medicinal use (Nascimento *et al.*, 2015; Ferreira *et al.*, 2020; Rondon *et al.*, 2020; Bagang *et al.*, 2024; Souza *et al.*, 2024).

CONCLUSIONS

Yams (*Dioscorea*) are a neglected crop in Brazil. There is no consistent information or propagation material to increase the scale of production, although there is great diversity in germplasm banks, in the possession of farmers or in native propagative material. This biodiversity, however, is very poorly understood, and essential information, such as distribution and environmental conditions for development, chemical and genetic composition, is available for only a minority of species or accessions or is not integrated. The cultivation of medicinal yams (barbascos) may become a new option for cultivation or extraction, but it needs to be further researched in Brazil.

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