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CARA BIOPRODUCTS (Dioscorea spp): a review study on the composition and applications

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Abstract

There are many articles discussing the properties, structures, modifications and applications of the starches from species of Dioscorea spp., due to the wide approach as a natural excipient, not just as innovation product in food and non-food industry, but also in laboratory. In this review, we found that several methods for isolation and modification of the Dioscorea spp. starches were and are in development by using modern implements. However, each technique has its own deficiency, and just a few have a substantial perform without modify starch at molecular level. The structure-application relationships of Dioscorea spp. starch have been better comprehended in the studies within pharmaceutical area as adjuvant agents for formulating pills and capsules. It's worth noting that, although has been a great advance on knowledge, functionality and utilization of Dioscorea spp. starch in industries, new approaches and innovations on how to apply its structural components will continue to emerge, based on recent techniques from primary research and experiments in animals or humans. From this perspective, sophisticated scientific inputs still need to be designed.

Keywords: Dioscorea; Yam; Composition; Application; Products

1. INTRODUCTION

Yam or Cará, as it's called in Amazonia, are generic names for a vast number of monocotyledon climbing plants species of the genus Dioscorea, considered the largest, most distributed and important pantropical family Dioscoreaceae in the order Dioscoreales, richly distributed in countries of South America, Africa, Asia, Caribbean islands and South Pacific (Mehrotra & Shukla, 2019).

The edible yam (Dioscorea spp.) cultivation, known as "li" or "yam", called "yampi" in Jamaica, "aja" in Cuba, "mapuey" in Puerto Rico, "cushcush" in western India, "ñames" or "igname", aparently owes it's names to African origins (Mehrotra; Shukla, 2019). The word yam was designated in Tupi as "ká rá" by the South American Indians, from where the term "Cará" comes from (Siqueira et al., 2011). Although the many popular names have variatons from one location to another, the starchy tubers are traditionally called "yam" (Romero-Hernández et al., 2019).

The species of Dioscorea genus had a wide spread throughout the world at the end of the Cretaceous period, after an evolution with different courses from the past to the present, giving rise to distinct species distributed into several sections (Ferreira et al., 2009). Due the similarity between the species, the cientific knowlege about those that coexisting on Earth is still very incipient in terms of its diversification and evolutionary process, as there are different views and theories. Given this scenario and, based on combined phylogenetic analyzes of morphological, molecular and sequence data, Mehrotra & Shukla (2019) estimate that Dioscorea consist in nearly 600 species arround the world as the closest to reality (Dutta, 2015; Romero-Hernández et al., 2019).

Few species of yam generate edible tubers, witch compose sources of cultural, economic and food security importance, as a primary diet for millions of people in the countries of South America, Africa, Asia and the Pacific. By the year 2018, world production of yams reached 72,580,851.00 tons in an area of 8,690,716.00 hectares (FAOSTAT, 2020).

Yam is currently one of the most important tuber crops in the world, preceded by potatoes (Solanum tuberosum L.) with 368,168,914.00 tons and cassava (Manihot esculenta C.) with 277,808,759.00 tons. The bigest yam producers are African tropical countries, especially the West Africa, also known as "yam zone", comprising Ivory Coast, Sierra Leone, Ghana, Benin, Nigeria and Ethiopia. According to FAOSTAT (2020), this area holds more than 96.4% of the yam world production, being Nigeria the largest producer with 33,025,893.20 tons. The South America, with 1,262,241.44 tons, is responsible 2.5% of the world production. Haiti, Brazil and Colombia are the main producers. In 2018 alone, Brazil produced 238,783.04 tonnes of yam.

In Africa (Tortoe et al., 2019), Asia (Andres et al., 2017), India (Ikiriza et al., 2019) and America (Da Costa et al., 2020) many studies have been conducted concerning starches of Dioscorea spp. functional potential, not just in the food industry, but also in film and drug productions.

The purpose of this study is to present a condition appraisal of the science in several species of yams (Dioscorea spp.), mainly the functional potential that were identified in their granules. The focus is provide a wide-ranging and up-to-date view on the investigations progress, as well as subsequent research challenges on the different applications of Dioscorea starch, based on information documented in the literature.

2. METHODOLOGY

Several research digital platforms, such as Google Scholar, popular global digital databases, including Science Direct, Springer, PubMed, Web of science, Scielo and Scopus were instruments in the search for relevant data. "Starch and dioscorea and applications" were chosen as the keywords to obtain relevant informations. After careful screening, data related to the current topic were extracted from 98 articles published from 1894 to 2020. The keywords for obtaining the information were also collected from published articles, master's and doctoral theses.

3. BOTANICAL PROFILE OF YAM (*Dioscorea spp.*)

The Dioscorea yams are identified as vegetables, allogamics and interlaced climbers (Beyerlein & Pereira, 2018), almost all herbaceous or shrubby. They belong to the Dioscoreales under the division Magnoliophyta (Kumar, 2017), semi-perennial or perennial whose life cycle varies between different cultivars, with a growth time of 8 to 36 months (Zhu, 2015), but ripen between 7 to 9 months after planting (Andres et al., 2017).

The species produce rhizomes or underground tubercles, but some species produce aerial tubers (Moorthy et al., 2018). The propagation occurs vegetatively using healthy tubers, or by seeds, as the plants are dioecious (Beyerlein, 2017; Castro et al., 2012), although there are fewer female plants than male plants, born separately or in separate plants. The tubers length can vary, as well as differ in shapes and colors of marrow (edible part) from white, yellow, dark brown, light purple, dark purple and mixed. They are sorted into: a) white yam (D. rotundata and D. cayenensis); b) water yam (D. alata); c) aerial potato (D. bulbifera) and d) bitter yam (D. dumetorum) (Andres et al., 2017). Usually the aerial stems are slender, cylindrical, glabrous and prickly. Some species has bulbils in the axillary buds adapted for vegetative propagation (Coursey, 1967). The leaves are green and simple, alternating ovate, corded or acuminate, some are lobed or webbed. The yams grow mostly in humid regions of warm tropical and subtropical forests, with few species in temperate areas around the world (Mehrotra & Shukla, 2019).

It has been suggested that yam is a primary crop grown in more than 50 countries, for example, the morphological differences between the varieties of species "A", "B", "C", "D", "F", "G "," H "visible in figure 1 are from the Asian continent and are distributed in the Americas, India and Africa. The species "E", "I", "J", "K", "L" are native and cultivated in the northeast, north, east and central regions of China (Zhu, 2015).

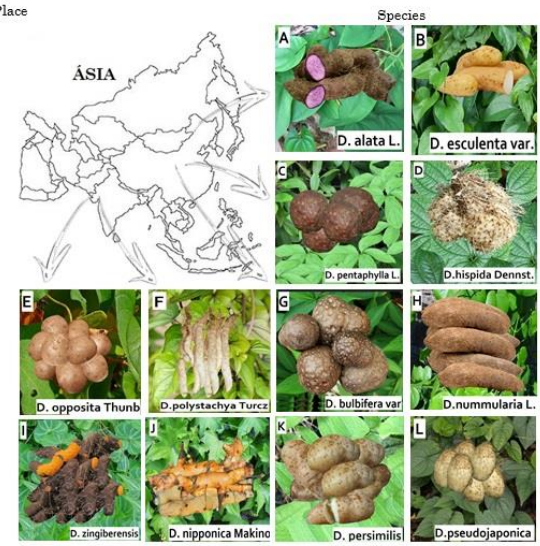

Figure 1. Photos of different Dioscorea plants distributed in Asia.
source: Daurimar Pinheiro Leão; Asia Map:
https://www.pinterest.ph/pin/789537378398804280/

The species "A", "B", "C", "F", "G" visible in figure 2, are cultivated and of West African origin (Ayensu & Coursey, 1972). The "D" and "E" species are grown in China (Zhu, 2015).

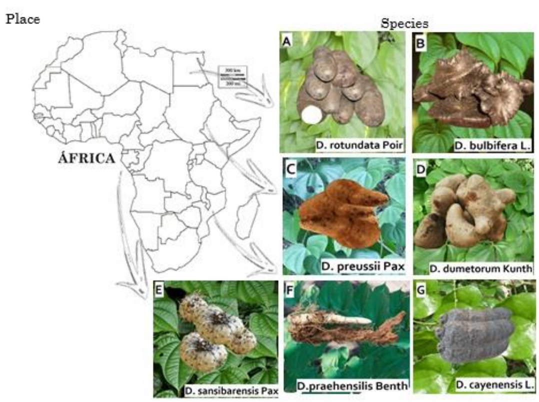

Figure 2. Photos of different Dioscorea plants distributed in Africa.
source: Daurimar Pinheiro Leão; Africa Map:
https://www.google.com/search?q=mapa+da+Africa

The species "B", "C" and "D" visible in figure 3, are described as original from the Americas. However, Caúper et al. (2006) argue that the origin and geographical distribution of "A" is the Amazon.

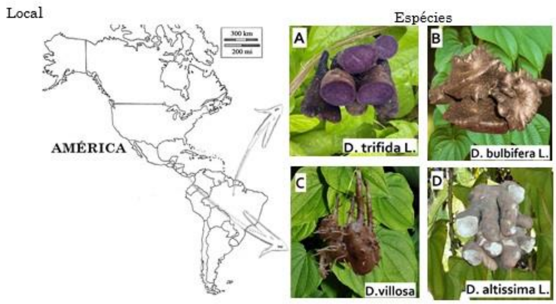

Figure 3. Photos of different Dioscorea plants distributed in America.
source: Daurimar Pinheiro Leão; America Map:
https://www.google.com/search?q=mapa+da+America

In Brazil, 140 species are accepted (Flora do Brasil 2020, 2020), linked to several regional names such as "cará" and "yam", among others (Victor et al., 2017). The species *D. trifida, D. alata, D. cayenensis, D. rotundata, D. esculenta and D. bulbifera* are distributed in the North, Northeast, Midwest, South and Southeast (Nascimento et al., 2013).

3.1. Composition of yam starch (*Dioscorea spp.*)

In Brazilian legislation, starch and farina are synonymous. Starch is denominated the fraction or starch product extracted from the edible aerial parts of vegetables. Farina is, therefore, the starch product extracted from the edible underground parts of vegetables. Starch and/or farina is an important vegetable structural homopolysaccharide, constitudes by repeated units of D-glucopyranosyl wich general formula is $(C_6H_{10}O_5)n$. It is a photosynthetic product of the cellular activity on plant green organs, including cereals, tubers, roots, fruits and seeds. It serves as a temporary food reserve of carbohydrates, providing them with energy for germination and photosynthesis in times of dormancy (Hornung et al., 2018; Shitan, 2016). Starch is the predominant fraction in Dioscorea tubers, but there are also useful bioactive compounds or secondary metabolites, which are categorized into alkaloids (Kanu et al., 2018).

Structurally, the starches polysaccharides of the Dioscorea species are polymorphs, presented in granules with a crystallinity of nearly 45-50%, classified as standard type A, B or C, maintained in different proportions of amylose and amylopectin (Zhu, 2015). Amylose is an important linear chain component of starch, formed by glucose units joined by glycosidic bonds. Amylopectin is a branched structure, formed by glucose units joined in $\alpha(1 \rightarrow 4)$ and $\alpha(1 \rightarrow 6)$. According to Hornung et al. (2017), the starch nature and function are influenced by the amylose/amylopectin ratio.

However, Magallanes-Cruz et al. (2017), Moorthy et al. (2018) claim that the shape of yam starch granules (regular, triangular, round, ellipsoid, ovoid), the average size of the granules diameters between 13 to 18 µm and the components arrangement in the amorphous and crystalline regions, also influence (González Vega, 2012). For this aspect, they are named “normal” starches, starches composed of 10 to 30% amylose and 70 to 90% amylopectin.

Therefore, in order to know the biochemical constituents of *Dioscorea* tropical tubers, several studies have been reported to focus on the levels of amylose in starch from different species of yam that, in general, presented an average value of 23.65% (González Vega, 2012), with high tendency to expansion, crystallinity, gelatinization parameters, bonding behavior (Hornung et al., 2017). In all those studies, smaller components such as proteins, lipids and ash were also found, with considerable discrepancies between the different reports.

In the literature, other biochemical constituents of the *Dioscorea* roots and the nutritional values potential began with the bioactive compounds tracking such as steroidal sapogenins, followed by qualitative tests on the genus species, to identify the alkaloids. In 1894, Boorsma first isolated the alkaline toxin dioscorin ($C_{13}H_{19}O_2N$) from the species *D. hirsuta*. Although some chemical constituents of *Dioscorea* yam have already been elucidated, it was Schutte (1897) who finally obtained the alkaloid dioscorin crystalline form. However, based on studies in degradation experiments, Gorter (1911) suggested that the alkaloid belonged to the tropane group. For Henry (1924), the alkaloid dioscorin identified in the species *D. hirsuta* and *D. hispida* showed high toxicity and a behavior similar to picrotoxin ($C_{30}H_{34}O_{13}$).

It is important to emphasize that many yam species, rich in bioactive compounds, have greater prominence for terpenoids which are formed by several units of monosaccharides (Eismann, 2019). In addition to biological activities, these properties function mainly as defense substances protecting them against microorganisms and fungi.

Due the great attempt to identify the *Dioscorea* chemical constituents, Coursey & Aidoo (1966) affirmed the presence of ascorbic acid in the chemical composition on the *Dioscorea* spp. species. However, it was the Ketiku and Oyenuga (1970) approaches that determined the total components of sugar, starch, amylose and amylopectin in the species *D. rotundata*.

In the *Dioscorea* roots, the main bioactive compounds are steroidal saponins. The above-ground part of the plant contains compounds based on phenanthrene, phenols and organic acids, coumarins, flavonoids, glycosides and polyols. In research by Harvey and Boulter (1983), the authors for the first time isolated *D. rotundata* dioscorin, with a molecular weight of about 31 kDa, responsible for 85% of the soluble proteins total content by alkaline tuber plugs. This discovery set a precedent for the adhesion of 31 kDa, as a monomeric molecular weight reference for the purified dioscorins of yam different species. In a later study, Kouassi et al. (1984) identified the glucose, fructose and sucrose rate in the *D. rotundata* and *D. alata* species and found the presence of maltose and hexose in the *D. esculenta* species.

Nowadays, several researches are conducted on the functional properties and the molecular structure of commercial starches obtained from seeds, tubers and roots, due to their ready availability. Although potatoes, wheat, cassava, rice and sorghum are starches sources, these are obtained from corn in national and international markets. This is because, generally, cereal grains contain from 40% to 90% of starch based on dry weight, immature fruits from 40% to 80% of dry weight, legumes from 30% to 50% and tubers, containing 65% to 85% (Santos Quesia, 2016).

In yam tubers, as in other roots, the starch yield (on a dry basis) can vary, but in general, they are considerably higher than cassava and corn (Ramos et al., 2014).

Guided by this approach, Akinoso & Abiodun (2013) detected a variation of 40.7% to 63.3% in the content of starch in the flour of *D. dumetorum*. Santos Samiria (2016) elucidated 75.6 to 84.3% of starch, mucilage and sugars as the main components of the *D. trifida* "cará" tuber.

The study by De Souza Silva (2020) with *D. trifida*, revealed 84.56% in the starch levels and 36.82% of amylose. Similarly, Silva et al. (2019) extracted and characterized the *D. altissima* and *D. alata* starch grown in Amazon. Were identified 84.63% of *D. alata* starch and 80.02% of *D.altissima*. The values ratify the important physical-chemical, technological, functional, morphological and thermal properties of yam starch in various industrial processes (Lovera et al., 2017). In the native starch granule, the amylose molecule can be complexed with lipids and influence the rheological properties of starch as greater tendency to retrograde and produce hard gels and strong films (Teixeira, 2016).

3.2. Chemical aspects of yam (*Dioscorea spp.*)

In the *Dioscorea* spp. tubers (on a dry basis), starch represents about 75 to 84%, 6 to 8% crude protein (dioscorin) and 1.2 to 1.8% crude fiber (Tang et al., 2019). In addition, most *Dioscorea* tubers are composed of several mineral phytochemicals such as magnesium, calcium, potassium, phosphorus, aluminum, copper, zinc, selenium, silicon, sodium, thiamine, tin, manganese, niacin, potassium, iron, cobalt, chromium , carbohydrates and soluble fibers (Pérez et al., 2012), B vitamins (thiamine, riboflavin, niacin, admin), provitamins A and D, vitamins C that can vary from 13.0 to 24.7 mg / 100 g (Ramos-Escudero et al., 2010), essential amino acids and fat levels (Feijó et al., 2016).

Several authors, (Jahan et al., 2019; Xue et al., 2019) have identified in *Dioscorea* spp. species the secondary metabolites divided into alkaloids, flavonoids (polyphenols), saponins, catechins, steroids, phenols and phenolic compounds, proanthocyanidin, anthocyanins, leucoanthocyanidin play an active role associated with plant defense strategies.

Alkaloids are the largest group of secondary metabolites, categorized into cyclic organic glycoside substances with an alkaline character. Phenolic compounds are responsible for generating the flavor, odor and color of the roots and rhizomes of *Dioscorea*. They have a great diversity of flavonoids and phenols, with antioxidant activity.

In the *Dioscorea* roots and rhizomes, an important class of substances are the steroids glycosides or polycyclic terpenes, with a sternutatory and irritating to mucous membranes structural characteristic, recognized by the detergent and emulsifying actions, in the formation of foam in *Dioscorea* extracts, because it has a hydrophilic or soluble part (glucose) and another lipophilic or fat soluble (triterpene or steroid) generically called sapogenin (furostanol or spirostanol). They are classified according to the aglycone number, and by their acidic, basic or neutral character. Neutral steroidal saponins are the main physiologically active constituents found in the *Dioscorea* family, whose aglycone unit is sapogenin linked to the oligosaccharide at the C-3 position, but can also be linked at positions C-27 (in steroidal saponins) or C30 (in triterpenoid saponins) (Eismann, 2019).

In China, other substances were found in different *Dioscorea* species such as phytic acid, glycoprotein, amino acids, ergosterol, choline, mucins (Qian, et al., 2019), polysaccharide, which includes hemicelluloses, grouped in mannose, arabinose, glucose, galactose, xylose and rhamnose, prosapogenin, epiafzelecin glucopyranoside, phytoestrogen, furanoid-norditerpene, oxalate and tannins (Kumar et al., 2017).

The non-enzymatic antioxidant effects, in particular of the *D. trifida* tuber led Ramos-Escudero et al. (2010) to a study for the anthocyanins composition. The levels of anthocyanidin pigments allowed to detect 12 derivative compositions. Among the compounds, peonidine, cyanidin and pelargonidin were identified, but peonidine 3-*O*-p-coumaroylglucoside-5-*O*-glucoside was the main flavonoid found.

4. YAM APPLICATIONS (*Dioscorea spp*.)

The properties of *Dioscorea* are primary sources of food for many populations in different parts of the world, associated with the great spectrum of biological activities and the long-term pharmacological potential, they are used for medical treatment in Asia.

However, the functional properties application of Dioscorea was claimed for the first time focusing on the *D. zingiberensis* rhizome potential, which were traditionally used as food and medicine by the Chinese people 2000 years ago (Zhang et al., 2018). In addition, several Chinese historical books have described the medicinal use of the plant.

The first written descriptions about the functional use of *Dioscorea* starch physicochemical components provide the foundation for multiple phytochemical and pharmacological explorations since the 1950s. In Malaysia, the natives discovered that mucilage of *D. piscatorum* tubers is useful for poison fish (Burkill, 1951).

In 1952, Irvine tested the dihydrodioscorine alkaloid toxic effect on the wild species *D. dumetorum* and *D. dregeana* mixed with bait and used as poisons to capture monkeys. Similarly, *D. hispida* dioscorin was used as a tiger poison by some tribes in Himalayas. Extracts of *D. sylvatica* species tubers have been used to treat uterine and breast disorders in animal models from Africa (Coursey, 1967). This author reports the pharmacological importance that employs several species of *Dioscorea* as a source of biologically active compounds.

In Rašper's study (1969), the gel-forming power was tested with starches from various *Dioscorea* species. It was observed that most yam starches produced very viscous pastes givin rise to very strong and short cooling gels, some of them with a retrograde high tendency. In another report, Martin (1969), identified the diosgenin alkaloid as the most important active ingredient in *Dioscorea* species, used in steroid drugs synthesis, such as progesterone, cortisol and estrogen.

4.1. Therapeutic properties and applications of yam (*Dioscorea spp.*)

Internationally, yam is a staple food easily digestible, widely used as a functional food in West Africa, Southeast Asia, the Caribbean and Taiwan as a medicine that guarantees its use in the synthesis of cortisone and other steroid hormones (Liu et al., 2007).

Aderiye et al. (1996) found a strong correlation between antifungal activity and protogracillin from the extract of the species *D. alata*. In an experimental phytochemical screening study of *Dioscorea spp.*, Sumastuti and Sonlimar (2002) identified that several secondary metabolites had biological effects, with antimicrobial, anti-inflammatory, anti-cancer and antioxidant activity to eliminate free radicals, lower cholesterol and glucose in the blood, antibiotic effect and immune improvement.

Other authors have associated such activities with the expression of diosgenin alkaloids, terpenoids and essential oils against *E. coli, S. aureus, A. fumigatus, A. niger, A. flavus, P. aeruginosa, P.*

vulgaris and P. nigricans (Roy et al., 2012). Lima et al. (2013) documented the use of *D. opposita* diosgenin in menopause hormone replacement therapy, dysmenorrhea, premenstrual tension, anti-inflammatory activities in testicular disorders, impotence, benign prostatic hyperplasia and psychosexual alterations. Kumar et al. (2017) identified correlations between immunomodulatory, antioxidant, antitumor, antimutagenic, hypoglycemic, antifungal, estrogenic, contraceptive and androgenic activities, gastric protector, immunostimulant and the high amounts of allantoin and dioscin extracted from Dioscorea species.

In Africa, the bioactive compounds common to some parts of the various *Dioscorea* species, are used for synthesis of steroid, anti-inflammatory, androgenic, estrogenic and contraceptive drugs (Asha; Nair, 2005). Saponins extracted by decoctions are used as component for shampoo, soap and insecticide (Sharma; Bastakoti, 2009).

In Nepal, *D.hamiltonii* tubers are macerated and administered for body cooling during the summer and for diarrhea. Also, formulations of the *D.bulbifera* species have clinical applications in the treatment of thyroid gland and as ophthalmic, anthelmintic, purgative, anti-inflammatory and hypoglycemic drugs in Diabetes (Ghosh et al., 2015).

In India and Africa, ethinomedical practices with properties of *D. bulbifera* have been associated with intestinal colic reduction, dysmenorrhea relief, acute phase severe inflammation, rheumatoid arthritis, spasmodic asthma and combating menopause problems, prevention of early abortion (Nayak et al., 2004). Furthermore, they are used as contraceptive, for sexual vigor, treatment of ulcers, hemorrhoids, tuberculosis, leprosy, syphilis, dysentery, cough, diabetes, and the powder used to kill lice (Ikiriza et al., 2019).

In *D. trifida* "cará" tubers, diosgenin and allantoin demonstrate antioxidant action, capable of eliminating radicals in vitro and in vivo (Mollica et al., 2013). Polysaccharides, resistant starch and dietary fiber, are used as antidiarrheal and antitussive (Park et al., 2013). In addition, maintain the skin, nerves and kidneys health, improve digestive process and delay aging (Dantas, 2014), because of its high redox potential and its ability to chelate metals.

Recent studies have reported the use of *D. nipponica* alkaloids in anti-inflammatory, analgesic and antitumor activity, on the cardiovascular system, respiratory tract, anti-aging, immune function regulation, thyroid regulation and antiplatelet aggregation. Also relate clinical applications in treatment of rheumatoid arthritis, low back and leg pains, traumatic injuries, chronic bronchial asthma and tumors (Ou-Yang et al., 2018). In the Chinese industry, the *Dioscorea spp.* yam polysaccharides have applications as functional and nutraceutical food, with effect on the respiratory tract, antibacterial, antioxidant, antimutagenic, hypoglycemic and analgesic, commonly used in the treatment of Kashin-Beck disease, heart disease and in steroid hormones synthesis (Huang et al., 2019). In addition, the polysaccharides and dioscorin of *Dioscorea spp.* are effective in lowering blood glucose, have physiological activities, such as carbonic anhydrase, dehydroascorbate reductase, anti-inflammatory, cytotoxic, antihypertensive and antifungal activities attributed to the aglycone portion of steroidal saponins (Lebot et al., 2019).

Considering the phytochemical effects, it is estimated that the *Dioscorea* species exhibit extensive effects with hypoglycemic and restorative body mass action, as it has anabolic, hormonal and antiallergic potential in the treatment of respiratory, heart and digestive diseases, reduces cholesterol, improves immunity, pancreatic function and lipid profile (Gong et al., 2019).

4.2. Food applications of yam starch (*Dioscorea spp.*)

In some countries in South and North America, Africa and Asia, yam species stand out as food due to their nutritional value. However, some species are consumed fresh or cooked, as a puree or soup ingredient, as well as flour in breads, cakes, pies, porridges, among others.

In the food industry, the functional properties of *Dioscorea* yam starches are used as an excipient for a wide range of applications. However, the physical-chemical and physical-mechanical properties of some species can not be used directly in applications, the starch needs to be modified using chemical, physical, enzymatic and biotechnological innovations to obtain more appropriate properties (Masina et al., 2017). In this context, the study by Ciacco and D'appolonia (1978) compared the structural and physico-chemical properties of yam (*D. alata*) with cassava flour (*Manihot utilissima*), which allowed the use of starch to produce food products. In this scope, Zaidul et al. (2008) analyzed the thermal and gluing properties of flour mixtures of *D. opposita* starch, wheat and other starches. It has been suggested that tuber starches may replace wheat flour in some food products preparation. Similarly, Nindjin et al. (2011) used flour composed of *D. cayenensis* and *D. alata* tubers, vegetables and cereals as an alternative source to produce breads and replace wheat flour.

Teixeira et al. (2013) examined the *D. trifica* starch properties in natura (in different concentrations) as an alternative to replace wheat flour in the bakery industry.

Recent studies show that *Dioscorea* starches are used as an excipient for the formulation of biodegradable films and compound flour (Zhu, 2015). Because of this, Reddy et al. (2014) suggested developing extruded made from *Dioscorea* tuber flours, with corn flours and black grass (*Ophiopogon japonicus*) to obtain snacks with sensory, physical-chemical and nutritional characteristics.

In Africa, the yam Bulbils of *D.bulbifera* species are boiled and used in ethnomedicine as food to treat HIV patients (Nabatanzi & Nakalembe, 2016). Fresh *D. hispida* yams are blanched, processed into chips and spread out to dry in the sunlight (Andres et al., 2017), then fried and served as a popular snack. Tortoe et al. (2019) used *D. alata* (*Akaba and Matches*) yam starches as a freezing source to thicken yoghurts. De Souza Silva (2020) extracted the *D. trifida* starch from the white cultivar and observed that the high amylose content could have a place in industry for food processes, film production and biodegradable packaging.

4.3. Yam starch film formation (*Dioscorea spp*.)

Several studies of yam starch have focused on formulations of extruded single screw gels to identify the extrusion variables effect. The extruded starch pastes formed opaque and firm gels, under specific conditions of food applications(Alves et al., 1999). In another study, Gomes (2008) extracted starch from *D. alata*, jalapa (*Operculina tuberosa*), taro (*Colocasia esculenta*) and green beans (*Vigna unguiculata*), prepared polymeric blends with chitosan and PVC, and obtained results in product packaging, agricultural mulchings, packaging for fruits, vegetables, compost bags, molded parts and dressings.

Silva (2010) reported the preparation and characterization of *D. esculenta* starch blends modified by oxidation and phosphorylation containing chitosan and PVA. The films showed potential as mulchings for membranes and / or hydrogels elaboration with antimicrobial activity. Pérez et al. (2012) found that the *D. trifida* native starch film of the white cultivar obtained by the cross-linking process had good width, opalescence and water permeability. According to the authors, with high potential to be used in the formulation of edible coatings or to obtain foams.

Gutiérrez et al. (2014) produced edible films based on phosphate-crosslinked native D. trifida yam starches, plasticized with glycerol and developed by smelting. It was analyzed and suggested that the characteristics of this culture films, are more promising for coating and packaging slightly acidic food products. Azman et al. (2016) produced polyacrylamide hydrogels grafted with *D. hispida* starch. It was observed that the polyacrylamide hydrogel extracts, grafted with starch, inhibited *Escherichia coli*, *Staphylococcus aureus*, *Salmonella typhimurium* and *Saccharomyces cerevisiae*.

Ashri et al. (2018) manufactured green hydrogel by reacting the chemically crosslinked *D. hispida* starch powder with sodium polyacrylate in the presence of potassium persulfate and studied the characteristics, swelling behavior and in vitro cytotoxicity. In one study, Lins (2018) obtained satisfactory viable results by producing films derived from yam starch (*D. alata* L.), purple sweet potatoes (*Ipomoes potatoes L.*) cassava starch (*Manihot esculenta Crantz*) as alternative packaging, for post-harvest conservation of tomatoes (*Lycopersicon esculentum* Mill).

Recently, the study by Silva et al. (2019) found that the *D. altissima* and D. *alata* starch have technological properties for the food industry and for the packaging production. In a study by Da Costa et al. (2020), the *D. trifida* starch flour associated with chitosan and glycerol were mixed to obtain biodegradable films in edible toppings, and to increase the shelf life of fresh fruits.

4.4. Pharmacological formulation of yam starch (*Dioscorea spp.*)

In addition to the starch films mentioned above, several studies in the biomedical field using appropriate isolation techniques reveal the application of *Dioscorea spp.* tubers starch as precursors in pharmaceutical field for controlled release of drugs that work as adjuvant agents in the tablets and capsules formulation. They can be used as thickeners, disintegrants, glidants or lubricants in powder form or as binders in mucilaginous form.

On this basis, the *D. villosa* yam was used as an adaptogen due to the effect similar to testosterone (anabolic), that is, because it helps in the normalization of the body system functions altered by stress (Bucci, 2000). Riley et al. (2006) reported the use of Dioscorea spp. yams starches as a precursor to pills production. In Nigeria, Oladebeye (2007) reported the use of D. dumetorum and D. alata starches as a binder in capsules and the paper industry.

Mollica et al. (2013) used starch from tubers of the genus D. zingiberensis and D. trifida as raw material to produce diosgenin, starting material for oral contraceptives, sex hormones and other steroids.

A similar observation was detected by Okunlola et al. (2015) when suggesting Pre-gelatinization, acetylation and characterization of D. dumetorum and D. oppositifolia starches, to be used as binders in pills formulations.

In the research by Chauhan et al. (2018) the diosgenin produced from D. zingiberensis, was administered as steroid hormones, for sexual dysfunction and contraceptives.

Other studies have demonstrated improvement and physical, chemical, enzymatic or genetic modification to produce starch with higher levels. Among them, Okunlola and Akingbala (2013), who used acid hydrolysis to modify the starch of D. oppositifolia, D. rotundata and D. alata in order to be used as a binder in pills formulation and disintegrant. Dauda et al. (2019) speculated the thermal modification of D. cayenensis starch in the binding and disintegration of tablets, using paracetamol as a drug.

4.5. Material for non-food applications

The waste starch from the good and rotten parts of the yam tuber was tested as a source of raw material for the production of bioethanol. This produced bioethanol with yields of 533 and 528 liters of alcohol per ton (LA / t), based on dry weight (Okolo & Agu, 2013).

In the study by Okunlola et al. (2017) the starches of D. dumetorum and D. oppositifolia were acetylated with acetic anhydride in the middle of pyridine, and used as polymers for the delivery of repaglinide in microsphere formulations. Victor et al. (2017) revealed that D. Trífida starch can be a promising biocatalyst for enzymatic systems, capable of reducing the fraction of pro-viral ß-keto esters in chiral ß-hydroxy-esters with moderate to good conversions and selectivities. In order to improve the cogeneration of cellulosic ethanol and methane from sugarcane and molasses with a combinatorial approach of ternary residues, Fan et al. (2019) explore, for the first time, the fermentation of mixed raw material from cellulose residues, D. composita starch and sugar. It was found that the production of biofuels from various raw materials, improved the efficiency of bioethanol generation with increased concentration of ethanol.

5. CONCLUSIONS

There are many articles discussing the properties, structures, modifications and applications of Dioscorea spp. Starches, due to the wide alternative approach as a natural excipient, both for innovations in commercial food and non-food production and in the laboratory. In this review, we found that several methods for isolating and modifying the starches of Dioscorea spp. were and are being developed using modern tools. However, each technique has unique deficiencies, and only a few play a considerable role, without generating major changes in morphology, such as attempts to modify starch at the molecular level. The structure-application relationships of Dioscorea spp. have been better understood in the pharmaceutical field as adjuvant agents for formulating pills and capsules. It therefore seems worthy to note that, although there has been a great advance in the understanding, functionality and application of Dioscorea spp. in industries. New approaches and innovations on the application of the structural components of Dioscorea spp. Starches will continue to emerge, with new techniques from basic research, experiments with animals and humans. From this perspective, instruments with sophisticated configurations still need to be designed.

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