DOI: https://doi.org/10.4038/java.v2i1.109

Journal of Agriculture and Value Addition, 2019, Vol. 2 (1): 43–59

REVIEW ARTICLE

Physical, chemical and biological aspects of *Dioscorea* yams and potential value additions

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Submitted: February 22, 2019; Revised: May 17, 2019; Accepted: May 31, 2019
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ABSTRACT

Dioscorea yams, which belong to the family Dioscoreaceae, have originated in African and Asian regions. At present, they are found in most of the tropical areas of the world and provide a great support to the world food production by generating a considerable amount of edible materials with minimum agricultural inputs. They have become a staple food for most of the African countries and thus numbers of value added yam products are found there. As a rich source of carbohydrates, energy, minerals, vitamins and bioactive compounds, yams have been defeating hunger and malnutrition while finding solutions for the food scarcity in African and Asian regions. Health benefits, such as anticancer properties, anti-diabetes properties, boosting retinal functions and cardiovascular disease prevention arise with yams in addition to delivering an extra value to the yams in food consumption systems of tropical regions of the world.

***Keywords**: Carbohydrates, Dioscorea yams, food scarcity, health benefits, staple food*

INTRODUCTION

Yams belong to the family *Dioscoreaceae* and the genus *Dioscorea* has originated from African and Asian regions of the world and later they have spread to the other parts of the world. Today, yams grow in most of the tropical regions of the world where environmental conditions are suitable. However, they can grow under less favorable environmental conditions which the other crops cannot tolerate. These starchy roots can produce huge edible masses with minimum agricultural inputs. Yams are consumed as primary, secondary or supplementary staple food of most of the African countries and Asian regions (Brunnschweiler, 2004; Baah, 2009).

Dioscorea yams are the third important tuber crop grown in tropics after cassava and sweet potatoes. Tuber part of *Dioscorea* crop is the most important part of the plant, which can store food for years and this is longer than the storage period of other root and tuber crops. Therefore, this will be a solution for food scarcity in the world. In addition to being the staple food, *Dioscorea* yams have made a great influence on the economic status of Caribbean islands, West Africa, Oceania and some parts of the Asia. Poor people in most of the African countries make income by selling *Dioscorea* yams and their processed products. Further, *Dioscorea* spp. have a ritual and socio-cultural value in these regions (Brunnschweiler, 2004; Fu *et al.*, 2005; Baah, 2009).

The worlds' largest yams producer is West Africa that produces 90% of the world production; it is 40 t of fresh produce per year. This amount provides >200 dietary calories for more than 60 million people daily. Jamaica is the second largest producer of yams followed by Tanzania and Sudan. Nigeria, Ghana, Togo, Ivory Coast, Philippines, Japan, Papua New Guinea and Panama also produce *Dioscorea* yams in large amounts per year (Dipeolu *et al.,* 2002; FAO, 2002; FAO, 2003; Brunnschweiler, 2004; Baah, 2009).

Most of the food prepared by using *Dioscorea* yams is unique to the particular region, culture and tradition. Therefore, very less industrial uses of these yams are reported. However, traditional utilisation potentials of these yams perform in a diverse range. Boiled, baked or fried yams are the most consumed forms of yams. Further, they are dried and converted in to a powder and this flour is used to produce number of food items such as cakes. Roasted or fried yams are often used as a snack. Boiled and crushed yams are regularly consumed with scraped coconut or with a gravy/sauce. Pulps of the yam tubers are prepared as porridge. Some of the *Diocorea* spp. are used for medicinal purposes. Ghana and Nigeria use to export fresh *Dioscorea* tubers and flour produced by these yams to USA and UK. Ghana is the world largest yams exporter and they export nearly 12,000 t of yams per year (Albrecht and McCarthy, 2006; Baah, 2009; Osibo, 2009; IITA, 2009).

Respiration occurring during the storage period of harvested yams leads to number of physiological and biochemical reactions which can reduce or enhance the quality of yams. For example, organoleptic properties of *D. alata* are improved during storage. Nonetheless, the optimum storage conditions that can improve the quality of *D. alata* have not been investigated yet. However, long storage life, higher nutritive value and high propagation yield of *Dioscorea* spp. creates a significant advantage as a food crop. Sensory properties of the food prepared by using yams determine the type and quantity of yams cultivated by farmers and consumed by consumers. These sensory properties are affected by the physico-chemical properties of these starchy roots. In addition to the sensory properties, *Dioscorea* yams are a good source of vitamins and minerals. (Tschannen *et al.*, 2003; Baah, 2009; Kulasinghe *et al.*, 2017; Kulasinghe *et al.*, 2018). Thus, the present review discusses the physical, chemical and biological aspects of *Dioscorea* yams and their potential value additions.

Edible types of *Dioscorea* yams, their physical structure and quality

There are around 600 *Dioscorea* spp. found all over the world and only few of them are recognised as edible species. Numerous types of them are useful and they can be utilised as edible food material. Certain types of them are poisonous and some of them are used only medicinally. There are other few species of *Dioscorea* used as important sources of raw materials of producing steroids and alkaloids. Some methods have been developed to detoxify some of the poisonous *Dioscorea* spp. However, 12 species of them are selected as nontoxic edible tubers. Only six species of them are consumed as food in tropical regions of the world. These main six species account for more than 95% of the consumed yams in the tropics. They are *D. alata*, *D. rotundata* L., *D. cayenensis* Lam, *D. esculenta* Lour, *D. bulbifera* L. and *D. trífida* L. In addition, *D. opposita* Thunb and *D. japonica* Thunb are grown and consumed in some of the temperate countries of the world. However, they are lesser-known crops in other regions of the world (Martin and Degras, 1978). 40 – 50 edible *Dioscorea* spp. are found in many parts of the world, which have started to disappear due to their less value and introduction of substitutes. Some of these edible *Dioscorea* spp. are shown in Table 1 (Martin and Degras, 1978).

Biological aspects of *Dioscorea* yams

Morphology of the *Dioscorea* spp. shows a wide range of diversity. Shape of *Dioscorea* tubers varies from globular shape to pear shape and from elongated shape to shapeless tubers (Figure 1). The surface of most of the yams is covered with lobes and small wiry roots. It makes yams difficult to peel. These yams are produced close to the surface of the soil or at deep levels of the soil. However, most of the poisonous *Dioscorea* yams grow near to the surface of the soil. Color of the flesh of these perennial tubers varies from white to light yellow and from purple to reddish/brown based on the pigment content such as anthocyanin and carotenoids. Unlike in other edible roots and tuber crops, some pigments of *Dioscorea* yams are not evenly distributed throughout the tissues and it creates unattractive appearance. Some of the pigments found in *Dioscorea* spp. are still unidentified. Sometimes, the surfaces of the yams are prickly and contain some ridges (Martin, 1976; Martin and Degras, 1978).

Sap of some *Dioscorea* species generates itchy and irritable feeling on skin during peeling and processing. Tender areas of human skin are more susceptible to these irritations which cause by calcium oxalate crystals that appear on freshly cut surfaces of the yams and they disappear after 10 – 15 min (Martin, 1976; Martin and Degras, 1978).

Yam tubers are recognised as dietary source comprising of different toxic substances that affect both human and animals when ingested, despite their high nutritional values.

Table 1: Lesser-known underutilised edible *Dioscorea* spp. found in different countries/regions as adapted from Martin and Degras (1978).

Country	*Dioscorea* spp.	
Ethiopia	*D. abyssinica* Höchst.	
Madagascar	*D. acuminata* Bak.	*D. mamillata* Jum. et Perr.
	D. analalavensis Jum. et Perr.	*D. nako* H. Perr.
		D. ovinala Baker.
	D. antaly Jum. et Perr.	*D. pteropoda* Boiv. ex H. Perr.
	D. bemandry Jum. et Perr.	*D. sambinarensis* R. Kunth.
	D. bemañvensis Jum. et Perr.	*D. seriflora* Jum. et Perr.
	D.flandra H. Perr.	*D. soso* Jum. et Perr.
	D. hexagona Bak.	*D. tanalarum* H. Perr.
	D. homhuka H. Perr.	*D. tricantha* Bak.
	D. macabiha Jum. et Perr.	*D. trichopoda* Jum. et Perr.
	D. maciba Jum. et Perr.	
Brazil	*D. adenocarpa* Mart.	*D. laxiflora* Mart. ex. Griesb.
	D. hastuta Mill.	*D. piperifolia* Humb. et Bonpl.
	D. heptaneura Veil.	*D. subhastata*
South America, Tropical America, Central America, Northern South America	*D. altissitna* Sieber ex Presl.	*D. convolvulácea* Cham, et Schlect.
	D. dodecaneura Veill.	*D. trífida* L.
	D. glandulosa Roxb.	*D. trifoliata* Grisebach.
Thailand	*D. arachnida* Prain et. Burk.	
Indochina	*D. arachnida* Prain et. Burk.	*D. oryzectorum* Prain et. Burk.
	D. cirrhosa Lour.	*D. depaupérala* Prain et. Burk.
	D. hamiltonn Hook.	*D. brevipetiolata* Prain et. Burk.
	D. pierrei Prain et. Burk.	
South Asia, Southeast Asia, East tropical Asia	*D. alata* L.	*D. kamoonensis* Kunth.
	D. bulbifera L.	*D. nummulaña* Lam.
	D. esculenta (Lour.) Burk.	*D. pentaphylla* L.
	D. gibbiflora Hook.	*D. persimilis* Prain et. Burk.
	D. glabra Roxb.	*D. puber* Bl.
	D. hamiltonn Hook.	*D. quinata* J. F. Gmel.
	D. hispida Dennst.	
West Africa, Tropical Africa, South Africa,	*D. bulbifera* L.	*D. praehensilis* Benth.
	D. cayenensis Lam.	*D. preussii* Pax.
	D. colocasiifolia Pax.	*D. pynaertii* de Wild.
	D. duynetorum (Kunth) Pax.	*D. quartiniana* A. Rich.
	D. elephantipes (I'Her.) Engl.	*D. rotundata* Poir.
	D. lecardi de Wild.	*D. sansibarensis* Pax.
	D. liebrechtsiana de Wild.	*D. schimperiana* Höchst.
	D. miniitiflora Engl.	*D. smilacifolia* de Wild.
Japan	*D. gracillinia* Miq.	*D. tenuipes* Franch. et Sav.
	D. quinqueloba Thunb.	*D. tokoro* Makino.
	D. septemloba Thunb.	
Philippines	*D. cumingii* Prain et. Burk.	*D. luzonensis* Schauer.
Western Australia	*D. hastifolia* Nees.	
Vietnam	*D. kratica* Prain et. Burk.	

Taiwan	*D. cirrhosa* Lour.	*D. matsudai* Hayata.
Malaysia	*D. puber* Bl.	*D. pyñfolia* Kunth.
China	*D.fargessii* Franch.	
Malaya	*D. flabellifolia* Prain et. Burk. *D. laurifolia* Wall. *D. orbiculata* Hook.	*D. piscatorum* Prain et. Burk. *D. polyclades* Hook. *D. prainiana* Kunth.
Congo	*D. semperflorens* Uline.	
Pacific Islands	*D. transversa* R. Brown.	
U.S.A.	*D. villosa* L.	

Most of yam tubers are acrid and they are associated with irritation and inflammation of the oral cavity and throat.

Some anti-nutritive factors available in some tubers cause allergy reactions on some individuals. Consumption can result in gastrointestinal troubles, vomiting and diarrhea mainly when large amounts are ingested into the human body. Anti-nutritional factors, which consist of polyphenols, oligosaccharides (α-galactosides), lectins, proteases and amylase inhibitors, are broadly dispersed in most plants. Age of the yam, cultivar, geographic locality of a plant or the storage condition after harvesting could significantly influence its anti-nutritional content. Utilisation of yams can be limited by the existence of toxic anti-nutrients. The presence of enzyme inhibitors in yams, for example could damage digestion of starch and protein thereby limiting their utilisation as a food (Bhandari and Kawabata, 2004; Medoua *et al*., 2007; Yang and Lin, 2008).

Chemical composition of *Dioscorea* yams

It is a rich source of carbohydrates and a good source of vitamins and minerals. High ash content of yams is a good indication for its high mineral content. Generally, yams contain high contents of dry matter and starch. Yam flour contains higher amounts of fiber than potato flour, refined wheat flour, maize and rice. High content of fiber and complex carbohydrates slow down the process of sugar absorption to the blood stream (Baah, 2009). However, chemical composition of the *Diocorea* yams varies with number of genetic and environmental factors. Many studies have shown that there are huge compositional variations detected even in the same subspecies grown in different areas (Kulasinghe *et al*., 2017).

Proximate Composition

There are number of scientists who have investigated the proximate composition of different *Dioscorea* subspecies. Table 2 shows the total carbohydrate contents of several *Dioscorea* spp. found in different parts of the world. Table 2 also shows number of variations of total carbohydrate content *Dioscorea* yams. However, compared to *Dioscorea* spp. *X. maffa* (Coco yam) contains comparatively low total carbohydrate content of 129.20±0.91 g kg^{-1} (Ukom *et al.,* 2014).

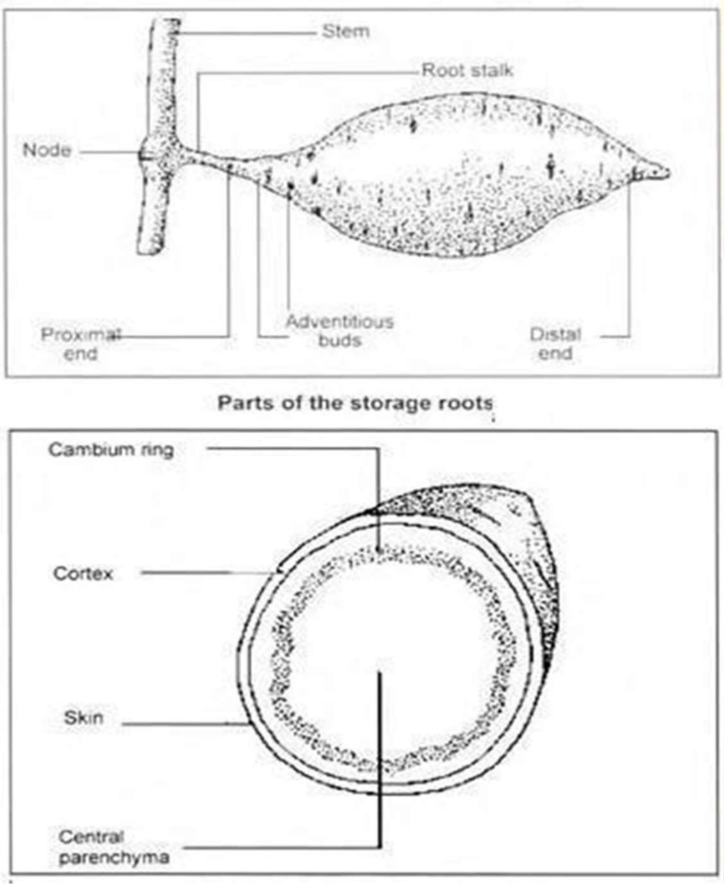

Figure 1: Typical cross section of a yam (FAO, 2010).

Moisture content of yams varies in a wide range due to number of reasons. Variety, species, age, soil conditions, relative humidity, post harvesting factors and geographical location of the plant are some of them. Table 3 shows the moisture contents of different *Dioscorea* yams and it provides sufficient evidence to prove above-mentioned factor.

Crude protein content of different *Dioscorea* yams are shown in Table 4. It varies from 0.08±0.03 to 10.16±0.64% (dry weight, DW). However, *Dioscorea* spp. are rich sources of carbohydrates. Protein content of these varieties is not significant since they are found in very low amounts. Crude protein content of *X. maffa* (Coco yam) was 71.51±1.32 g kg^{-1} which is higher than the crude protein contents (dry weight basis) of *Dioscorea* yams (Ukom *et al.*, 2014).

Table 2: Total carbohydrate content of *Dioscorea* yams.

Dioscorea spp.	Total carbohydrate content (%)	Reference
D. alata (*Rajala*)	75.86±2.01 (DW)	Senanayake *et al*. (2012)
D. alata (Hingulara)	78.32±1.14 (DW)	*Senanayake et al.* (2012)
D. esculenta (Kukulala)	74.66±0.66 (DW)	*Senanayake et al.* (2012)
D. alata (Rajala)	23.48±0.32 (FW)	*Kulasinghe et al.* (2017)
D. alata (Angili ala)	24.02±0.32 (FW)	*Kulasinghe et al.* (2017)
D. esculenta (Kukulala)	26.84±0.94 (FW)	*Kulasinghe et al.* (2017)
D. pentaphylla (*Katuala*)	18.30±0.21 (FW)	Kulasinghe *et al*. (2017)
D. rotundata subspecies	85.51± 1.21 – 87.31± 0.07 (DW)	Polycarp *et al*. (2012)
D. praehensalis	82.52±0.31 (DW)	Polycarp *et al*. (2012)
D. dumetorum (White and Yellow subspecies)	77.53±0.59 – 77.91±0.12 (DW)	Polycarp *et al*. (2012)
D. esculenta subspecies	79.84±0.98 – 80.05±0.46 (DW)	Polycarp *et al*. (2012)
D. alata subspecies (5)	90.10±0.29 – 92.50±0.33 (DW)	Sajiwanie and Rathnayaka (2016)
D. cayenesis (Yellow yam)	29.45±0.24 (DW)	Ukom *et al.* (2014)
D. dumetorum (Trifoliate yam)	15.18±1.18 (DW)	Ukom *et al.* (2014)
D. bulbifera (Aerial yam)	20.46±1.03 (DW)	Ukom *et al.* (2014)
D. alata subspecies (16)	74.40 and 60.30 (DW)	Baah *et al*. (2009)
D. rotundata (White yam)	40.61± 0.02 (DW)	Alinnor and Akalezi, 2010

Table 5 shows the crude fat content of *Dioscorea* yams. Crude fat content of *D. alata* subspecies appear higher than *Amorphophallus paenoiifolius* (Elephant foot yam) (0.32±0.06%) on dry weight basis (Sajiwanie and Rathnayaka, 2016). Crude fat contents of *Dioscorea* spp. are higher than that in *X. maffa* (Coco yam); it contains 2.20±0.35 g kg^{-1} of crude fat (Ukom *et al*., 2014). Alinnor and Akalezi (2010) prove that of crude fat of *Dioscorea* spp. is higher than in *Colocasia esculenta* (White coco yam) (1.05±0.01%).

Table 6 shows the ash contents found in different *Dioscorea* yams. Ash content of *D. alata* (*Rajala*) and *D. alata* (*Hingurala*) are similar to the ash content of *X. sagittifolium* (*Kiriala*) (Senanayake *et al*., 2012). However, ash content of *Amorphophallus paenoiifolius* (Elephant foot yam) (5.88±0.03%) is higher than the ash content of *D. alata* subspecies (Sajiwanie and Rathnayaka, 2016). This value for *X. maffa* (Coco yam) was 47.29±1.28 g kg^{-1} which is higher than the ash content (dry weight basis) of *Dioscorea* yams investigated (Ukom *et al*., 2014).

Table 7 shows the crude fiber content of *Dioscorea* yams. It ranges from 0.70±0.01 to 3.47±0.92%. However, Baah *et al.* (2009) shows that the total dietary fiber content of *D. alata* subspecies ranges from 4.1 to 11.0%.

Table 3: Moisture content of *Dioscorea* yams.

Dioscorea spp.	Moisture content (%)	Reference
D. alata (*Rajala*)	66.54±0.81	Kulasinghe *et al* (2017)
D. alata (*Angili ala*)	65.53±0.38	Kulasinghe *et al.* (2017)
D. esculenta (*Kukulala*)	62.61±0.65	Kulasinghe *et al.* (2017)
D. pentaphylla (*Katuala*)	73.15±0.64	Kulasinghe *et al.* (2017)
D. rotundata subspecies	58.18± 1.22 – 63.23±0.24	Polycarp *et al.* (2012)
D. bulbifera	68.60±1.72 to 64.13±1.44	Polycarp *et al.* (2012)
D. cayenensis subspecies	68.58±0.84 – 68.99±0.85	Polycarp *et al.* (2012)
D. praehensalis	64.06±0.63	Polycarp *et al.* (2012)
D. dumetorum (White and Yellow subspecies)	75.68±0.22 – 79.26±1.80	Polycarp *et al.* (2012)
D. esculenta subspecies	77.15±1.86 – 76.79±0.13	Polycarp *et al.* (2012)
D. alata subspecies (5)	69.0±0.06 – 84.3±0.27	Sajiwanie and Rathnayaka (2016)
D. alata subspecies (16)	66.20 – 77.70	Baah *et al.* (2009)
D.cayenesis (Yellow yam)	62.21±0.08	Ukom *et al.* (2014)
D. dumetorum (Trifoliate yam)	69.05±0.52	Ukom *et al.* (2014)
D. bulbifera (Aerial yam)	65.31±0.17	Ukom *et al.* (2014)

Minerals

D. alata, which is the most consumed variety of *Dioscorea* yams, comprises different compositions of minerals based on the subspecies. Baah *et al.* (2009) have clearly shown this variation by presenting the mineral compositions of 16 *D. alata* subspecies. They observed that phosphorous (P) content varies from 878 to 1900 mg kg^{-1}, calcium (Ca) content from 260 to 410 mg kg^{-1}, magnesium (Mg) content from 390 to 580 mg kg^{-1} and sodium (Na) content between 84 and 131 mg kg^{-1}. However, proving that *D. alata* subspecies are a perfect source of potassium (K), Baah *et al.* (2009) have shown that the K content of *D. alata* subspecies range between 10,550 and 20,100 mg kg^{-1}. Furthermore, manganese (Mn) content of *D. alata* subspecies varies from 4.8 and 22.1 mg kg^{-1} while copper (Cu) content varies between 12.3 and 15.7 mg kg^{-1}. Zinc (Zn) content of *D. alata* subspecies ranges between 10.1 and 14.1 mg kg^{-1} (Baah *et al.* 2009).

Table 4: Crude protein content of *Dioscorea* yams.

Dioscorea spp.	Crude protein content (%)	Reference
D. alata (*Rajala*)	10.16±0.64 (DW)	Senanayake *et al*. (2012)
D. alata (*Hingurala*)	6.24±0.26 (DW)	Senanayake *et al*. (2012)
D. esculenta (*Kukulala*)	9.02±0.65 (DW)	Senanayake *et al*. (2012)
D. alata (*Rajala*)	1.91±0.06 (FW)	Kulasinghe *et al.* (2017)
D. alata (*Angili ala*)	1.34±0.06 (FW)	Kulasinghe *et al.* (2017)
D. esculenta (*Kukulala*)	1.30±0.00 (FW)	Kulasinghe *et al.* (2017)
D. pentaphylla (*Katuala*)	1.65±0.09 (FW)	Kulasinghe *et al.* (2017)
D. rotundata	0.087±0.03 (DW)	Alinnor and Akalezi (2010)
D. alata subspecies (16)	4.30 – 8.70 (DW)	Baah *et al*. (2009)
D. cayenesis (Yellow yam)	3.19±0.08	Ukom *et al*. (2014)
D. dumetorum (Trifoliate yam)	6.92±4.49	Ukom *et al*. (2014)
D. *bulbifera* (Aerial yam)	3.71±4.54	Ukom *et al*. (2014)
D. alata subspecies (16)	5.10±0.10 – 7.60±0.24 (DW)	Sajiwanie and Rathnayaka (2016)
D. rotundata subspecies	4.42± 0.18 – 4.03±0.87 (DW)	Polycarp *et al*. (2012)
D. bulbifera subspecies	5.38±0.43 – 5.30±0.43 (DW)	Polycarp *et al*. (2012)
D. cayenensis subspecies	5.78±0.12 – 5.30±0.03 (DW)	Polycarp *et al*. (2012)
D. praehensalis	5.38±0.31 (DW)	Polycarp *et al*. (2012)
D. dumetorum (White and Yellow subspecies)	6.21±0.25 – 6.52±0.56 (DW)	Polycarp *et al*. (2012)
D. esculenta subspecies	5.60±0.37 – 5.73±0.19 (DW)	Polycarp *et al*. (2012)

Baah *et al*. (2009) and, Sajiwanie and Rathnayaka (2016) have shown that the K content of *D. alata* subspecies varies between 114.04 and 206.83 mg 100 g^{-1} and Na content between 1.45 and 3.25 mg 100 g^{-1}. Mg content of *D. alata* subspecies ranges between 11.11 and 22.20 mg 100 g^{-1}. Further, according to Sajiwanie and Rathnayaka (2016), *D. alata* subspecies comprise of 0.47 – 0.87 mg 100 g^{-1} of Zn, 0.71 – 2.29 mg 100 g^{-1} of Cu and 0.99 – 2.49 mg 100 g^{-1} of iron (Fe). Kulasinghe *et al*. (2017) showed that 5120±0.22 µg g^{-1} of K content, 170±0.00 µg g^{-1} of Mg content, 40±0.00 µg g^{-1} of Na content, 5.92±0.08 µg g^{-1} of aluminum (Al) content, 0.52±0.08 µg g^{-1} of Ca content, 15.95±1.25 µg g^{-1} of Zn content, 4.48±0.04 µg g^{-1} of copper content, 23.47±0.32 µg g^{-1} of Fe content and 1.98±0.25 µg g^{-1} of Mn content available in *D. alata* (*Rajala*) on fresh weight basis.

According to Alinnor and Akalezi (2010), *D. rotundata* contains 185.15±0.05 mg 100 g^{-1} of Na, 209.13±0.03 mg 100 g^{-1} of K, 132.02±0.04 mg 100 g^{-1} of Ca, 45.90±0.02 mg 100 g^{-1} of Mg, 81.85±0.01 mg 100 g^{-1} of Fe, 10.06±0.05 mg 100 g^{-1} of Cu, 5.46±0.02 mg 100 g^{-1} of Zn and 54.00±0.04 mg 100 g^{-1} of P. According to Kulasinghe *et al*. (2017), 4,900±0.24 µg g^{-1} of K content, 200±0.02 µg g^{-1} of Mg content, 20±0.00 µg g^{-1} of Na content, 5.88±0.14 µg g^{-1} of Al content, 0.44±0.01 µg g^{-1} of Ca content, 15.69±0.03 µg g^{-1} of Zn content, 3.61±0.00 µg g^{-1} of

Cu content, 16.80±2.96 µg g^{-1} of Fe content and 4.42±0.10 µg g^{-1} of Mn content available in *D. esculenta* on fresh weight basis.

Table 5: Crude fat content of *Dioscorea* yams.

Dioscorea spp.	Crude fat content (%)	Reference
D. alata subspecies	0.51±0.04 – 1.71±0.02 (DW)	Sajiwanie and Rathnayaka (2016)
D. alata (*Rajala*) (*Angili ala*)	0.06±0.02 (FW)	Kulasinghe *et al*. (2017)
D. alata (*Angili ala*)	0.11±0.008 (FW)	Kulasinghe *et al*. (2017)
D. esculenta (*Kukulala*)	0.18±0.02 (FW)	Kulasinghe *et al*. (2017)
D. pentaphylla (*Katuala*)	0.06±0.02 (FW)	Kulasinghe *et al*. (2017)
D. alata (*Rajala)*	1.53±0.31 (DW)	Senanayake *et al*. (2012)
D. alata (Hingurala)	1.56±0.25 (DW)	Senanayake *et al*. (2012)
D. esculenta (*Kukulala*)	1.5±0.2 (DW)	Senanayake *et al*. (2012)
D.cayenesis (Yellow yam)	0.44±0.19	Ukom, *et al*. (2014)
D. dumetorum (Trifoliate yam)	0.37±0.16	Ukom, *et al*. (2014)
D.bulbifera (Aerial yam)	0.34±0.14	Ukom, *et al*. (2014)
D. rotundata (White yam)	0.27±0.02 (DW)	Alinnor and Akalezi (2010)
D. rotundata subspecies	0.41± 0.00 – 0.46±0.07 (DW)	Polycarp *et al*. (2012)
D. bulbifera subspecies	0.55±0.17 – 0.53±0.02 (DW)	Polycarp *et al*. (2012)
D. cayenensis subspecies	0.50±0.07 – 0.53±0.07 (DW)	Polycarp *et al*. (2012)
D. praehensalis	0.48±0.28 (DW)	Polycarp *et al*. (2012)
D. dumetorum (White and Yellow subspecies)	0.61±0.18 – 0.61±0.06 (DW)	Polycarp *et al*. (2012)
D. esculenta subspecies	0.76±0.06 – 0.73±0.03 (DW)	Polycarp *et al*. (2012)

Further, Kulasinghe *et al*. (2017) quantified different elemental composition and accordingly, 4,610±1.34 µg g^{-1} of K content, 250±0.02 µg g^{-1} of Mg content, 30±0.00 µg g^{-1} of Na content, 10.59±0.03 µg g^{-1} of Al content, 0.85±0.03 µg g^{-1} of Ca content, 37.58±0.26 µg g^{-1} of Zn content, 3.81±0.03 µg g^{-1} of Cu content, 26.99±1.36 µg g^{-1} of Fe content and 2.39±0.14 µg g^{-1} of Mn content available in *D. pentaphylla* on fresh weight basis. *D. alata* (*Angili ala*) contains 4,750±0.49 µg g^{-1} of K content, 210±0.02 µg g^{-1} of Mg content, 260.0±0.00 µg g^{-1} of Na content, 10.99±0.38 µg g^{-1} of Al content, 0.51±0.07 µg g^{-1} of Ca content, 9.82±1.90 µg g^{-1} of Zn content, 2.88±0.11 µg g^{-1} of Cu content, 25.63±3.44 µg g^{-1} of Fe content and 1.81±0.79 µg g^{-1} of Mn content on fresh weight basis (Kulasinghe *et al.*, 2017).

Arsenic (As) and cadmium (Cd) contents of *D. alata* (*Rajala* and *Angili ala*), *D. esculenta* and *D. pentaphylla* remain between 0.1 and 0.008 µg g^{-1} which were below the harmful level to the human body (Kulasinghe *et al.*, 2017).

Table 6: Ash content of *Dioscorea* yams.

Dioscorea spp.	Ash content (%)	Reference
D. alata (*Rajala*)	1.66±0.21	Senanayake *et al*. (2012)
D. alata (*Hingurala*)	2.33±0.15	
D. esculenta (*Kukulala*)	2.10±0.20	
D. alata subspecies (16)	2.90 to 4.10	Baah *et al*. (2009)
D. alata subspecies (5)	1.72±0.02 – 3.11±0.01	Sajiwanie and Rathnayaka (2016)
D. alata (*Rajala*)	0.64±0.15	Kulasinghe *et al*. (2017)
D. alata (*Angili ala*)	0.65±0.006	Kulasinghe *et al*. (2017)
D. esculenta (*Kukulala*)	0.76±0.003	Kulasinghe *et al*. (2017)
D. pentaphylla (*Katuala*)	0.84±0.05	Kulasinghe *et al*. (2017)
D. cayenesis (Yellow yam)	1.96±0.06	Ukom *et al*. (2014)
D. dumetorum (Trifoliate yam)	2.84±0.06	Ukom *et al*. (2014)
D. bulbifera (Aerial yam)	3.01±0.28	Ukom *et al*. (2014)
D. rotundata subspecies	1.29±0.11 – 2.57±0.27	Polycarp *et al*. (2012)
D. bulbifera subspecies	8.15±0.37 – 7.73±0.67	Polycarp *et al*. (2012)
D. cayenensis subspecies	5.48±0.76 – 5.22±0.14	Polycarp *et al*. (2012)
D. praehensalis	4.90±0.28	Polycarp *et al*. (2012)
D. dumetorum (White and Yellow subspecies)	7.79±0.19 – 7.79±0.03	Polycarp *et al*. (2012)
D. esculenta subspecies	8.50±0.55 – 7.57±0.62	Polycarp *et al*. (2012)

Vitamins

D. pentaphylla contained 26.25±1.09 µg 100 g^{-1} of vitamin A, however; vitamin D, K, and E are not found (Kulasinghe *et al*., 2017). 1.28±0.02 mg 100 g^{-1} of vitamin B1 and 2.93±0.02 mg 100 g^{-1} of vitamin B2 were found in *D. pentaphylla. D. alata* (*Rajala* and *Angili ala*) contains only vitamin K (0.74±0.00 µg 100 g^{-1} and 0.68±0.01 µg 100 g^{-1}) from fat soluble vitamins and *Rajala* contains 1.04±0.00 mg 100 g^{-1} of vitamin B1 and 0.76±0.00 mg 100 g^{-1} of vitamin B2 while *Angili ala* comprises with 0.34±0.02 mg 100 g^{-1} of vitamin B1 and 2.61±0.03 mg 100 g^{-1} of vitamin B2. *D. esculenta* contained no any fat soluble vitamins but consists with 0.66±0.02 mg 100 g^{-1} of vitamin B1 and 2.49±0.01 mg 100 g^{-1} of vitamin B2 (fresh weight basis) (Kulasinghe *et al*., 2017).

D. alata consists with 0.44±0.10 mg 100 g^{-1} vitamin C, 0.03±0.20 mg 100 g^{-1} vitamin B3, 0.008±0.10 mg 100 g^{-1} vitamin B2 and 0.008±0.20 mg 100 g^{-1} vitamin B1. Meanwhile, *D. cayenesis* contains 1.23±0.11 mg 100 g^{-1} of vitamin C, 0.13±0.21 mg 100 g^{-1} of vitamin B3, 0.004±0.11 mg 100 g^{-1} of vitamin B2 and 0.007±0.10 mg 100 g^{-1} of vitamin B1. *D. bulbifera* contained 1.67±0.22 mg 100 g^{-1} of vitamin C, 0.01±0.02 mg 100 g^{-1} of vitamin B3, 0.009±0.12 mg 100 g^{-1} of vitamin B2 and 0.009±0.20 mg 100 g^{-1} of vitamin B1. *D. rotundata* contained 1.10±0.10 mg 100 g^{-1} of vitamin C, 0.31±0.02 mg 100 g^{-1} of vitamin B3, 0.009±0.20 mg 100 g^{-1} of vitamin B2 and 0.01±0.20 mg 100 g^{-1} of vitamin B1. *D. belophylla* contains 1.67 mg 100 g^{-1} of vitamin C, 0.70 mg 100 g^{-1} of vitamin B1 and 0.43 mg 100 g^{-1} of vitamin B2 (Okwu and Ndu, 2006; Poornima and Ravishankar, 2009).

Table 7: Crude fiber content of *Dioscorea* yams (DW).

Dioscorea spp.	Crude fiber content (%)	Reference
D. alata subspecies	1.01±0.07 – 2.30±0.27	Sajiwanie and Rathnayaka (2016)
D. rotundata	0.70±0.01	Alinnor and Akalezi, (2010)
D. cayenesis (Yellow yam)	2.73±0.16	Ukom *et al.* (2014)
D. dumetorum (Trifoliate yam)	5.65±0.41	Ukom *et al.* (2014)
D. bulbifera (Aerial yam)	7.10±0.74	Ukom *et al.* (2014)
D. rotundata subspecies	1.68±0.18 – 1.25±0.32	Polycarp *et al.* (2012)
D. bulbifera subspecies	2.35±0.38 – 2.03±0.34	Polycarp *et al.* (2012)
D. cayenensis subspecies	1.91±0.40 – 2.44±0.58	Polycarp *et al.* (2012)
D. cayenensis subspecies	1.91±0.40 – 2.44±0.58	Polycarp *et al.* (2012)
D. praehensalis	1.41±0.10	Polycarp *et al.* (2012)
D. dumetorum (White and Yellow subspecies)	3.47±0.92 – 2.10±0.01	Polycarp *et al.* (2012)
D. esculenta subspecies	2.19±0.11 – 2.34±0.03	Polycarp *et al.* (2012)

Antioxidant activity and anti-nutritive substances

Plenty of studies have shown that *Dioscorea* yams have diverse nutrients and non-nutritive substances. Most of them show bioactive properties. Phenolic compounds, organic acids, flavonoids and color pigments are some of them. Extraction of these materials are solvent specific. Different compounds can be harvested using different solvents in different levels. Method of preparation of yams also affects the bioavailability of these substances. Therapeutic properties of these compounds have been taking into the consideration in traditional medicine since antiquity. Free radical scavenging activity of these compounds plays a vital role in delaying cell aging, cancer prevention, prevention of degenerative illnesses, liver protection, avoiding coronary heart diseases and boosting retinal functions. Some of the *Dioscorea* yams are used in some countries to produce medicines for diarrhea and diabetes. Some of these yam extracts are used to reduce blood sugar of diabetes patients as well as they are used as antimicrobial solutions. These properties are found in *Dioscorea* yams due to the antioxidants available in them (Bhandari and Kawabata, 2003; Liu *et al.,* 2006; Cornago *et al.*, 2011; Shajeela *et al.*, 2011; Roy *et al.*, 2011; Das *et al.*, 2012; Sakthidevi and Mohan, 2013; Kumar *et al.*, 2017; Tamaro *et al.,* 2018).

D. alata subspecies are highly used in India as a cytotoxic, immune-regulatory, antifungal, hypoglycemic medicine with anti-tumor, and cardiovascular treatment properties. It is commonly consumed as anti-inflammatory, estrogenic, androgenic, and contraceptive drugs. Antioxidant activity of *Dioscorea* yams is popular in China to treat chronic diarrhea, poor appetite, dry cough, asthma, diabetes, uncontrolled urination, emotional instability, abscesses, ulcers and tumors. *Dioscorea futschauensis* contains Diosgenin-3-O-α-l-rhamnopyranosyl-(1→4)-β-d-glucopyranoside (DRG), which is a pentacyclic triterpene glycoside, used in many cancer treatments successfully (Das *et al.*, 2012). The anti-nutritional factors such as phenolic compounds, hydrogen cyanide, tannins, oxalate, trypsin inhibitor and amylase inhibitor activities are found in most of the edible *Dioscorea* yams. However, drying, cooking, soaking, steaming and heat treatments can be used to inactivate these compounds and make it more palatable (Shajeela *et al.*, 2011).

Value added food products of *Dioscorea* yams

Fresh yams are peeled and boiled or roasted or fried to prepare the most common dishes often consumed in many parts of the world. Instead of these dishes, there are numerous traditional and commercially available food products prepared by using *Dioscorea* yams (Abass, 2003; Baah, 2009).

Pounded yams are one of the very common dishes prepared in African countries which provides a balanced diet. Boiled yams are peeled, sliced and mashed in to paste by using mortar and pestle. It is consumed with a soup contain vegetables and meat or fish. *Fufu* is another dish very similar to pounded yams. Cooked yams are mashed until it turns into an elastic dough and combined with bananas and Cocoyam. This is consumed with s soup and popular in Ghana (Baah, 2009).

Another popular fermented product produced by yams is *elubo*. Peeled, sliced fresh yams are parboiled at 60 – 66 °C in water. It is well covered and kept for 24 h for fermentation using natural micro flora. The water is drained and slices of yams are dried to produce *elubo*. *Elubo* is available in Nigerian market throughout the year. Therefore, preparing yams as *elubo* is one of the preservation method used in Nigeria. *Elubo* is milled in to a fine powder by using a traditional mortar and pestle. This powder is turned into thick paste by mixing with four parts of boiling water to produce Nigerian delicacy named *amala*. The same product is prepared in Benin and they call it as *telibo* (Baah, 2009).

Farmers of many parts of the world cultivate yams are used to place washed fresh whole yams or chunks of yams under hot coal or firewood or in earthen ovens. Farmers at farmers' fields consume these roasted yams in the past and today it is a popular street food in Ghana and Nigeria like African countries. It is served with red palm oil or salted roasted fish as a street food (Baah, 2009).

Ikokore or *ikpankwukwo* is a Nigerian traditional dish prepared by using *D. alata*. Grated fresh yams are whipped thoroughly and scooped in to sauce contain pepper, fish, salt, palm oil and some other ingredients. It is steamed over fire at low heat until it is cooked. These traditional food products prepared by yams have directed the path to produce industrial products (Akissoe *et al.,* 2001; Baah, 2009).

In addition, yam flour can be converted into puffed snack by mixing with maize flour, pepper powder, water, salt and extruding this mixture by using an extruder. Drying of flattened mixture of tuber flour, black gram flour, salt, oil, water and sodium bicarbonate results an Indian food called *Papad* (Parvathi *et al.*, 2016).

Sun drying and milling of yams produce yam flour and yam flakes, which have good local and international market. Preparing yams as dried yams chips and pellets avoids post-harvest loses and deterioration and wastage. Milling of these dried yams chips and pellets results yam flour which can be used in bakery products, weaning food and plant based beverages. However, drying and milling is the only possible unit operations used in adding value to yams at domestic level as well as industrially reported until now. This can be practiced either to fresh yams or to cooked or boiled yams. Pounded yams are drum dried to produce *poundo* yam flour or *poundo* yam flakes which are being produced industrially. Cleaning, peeling, cooking, mashing and drying are the basic unit operations involved in this process. Drum dryers, roller dryers or cabinet dryers are used in drying this product in to flakes and these flakes are milled in to powder to produce *poundo* yam flour. *Poundo* yam flour or *poundo* yam flakes are then packed in airtight packages and sent to the market or exported to UK, USA and some other European countries. Consumers buy these products and make them as porridge or add boiling water and turn it in to dough to produce different food products. They are good convenient products for busy urban life styles due to their easy preparation processes. Currently, this flour is used widely for baked products such as breads, puffed products, cookies, cakes, tarts and pies (Mestres *et al.*, 2004; Baah, 2009; Bibiana *et al.*, 2015).

CONCLUSIONS

There are number of *Dioscorea* yams found in different areas of the world. Important intra-species and inter-species differences make available physical, chemical and biological properties of *Dioscorea* yams. High quantities of carbohydrate and energy with appreciable levels of minerals, vitamins and antioxidants make *Dioscorea* yams nutritious and they are a reliable food and energy security crop. Yams are usually poor in proteins. Thus, it is vital to combine with protein sources to make it wholesome. K, Mg, Na, Zn and Fe are the most predominant minerals found in *Dioscorea* yams. Composition of these yams can vary with number of factors such as geographical location, soil and environmental factors, variety, growing conditions and diseases. They contain various amounts of phenolic compounds, oxalates, amylase inhibitors, tannins, hydrogen cyanide and trypsin inhibitor like anti-nutritive substances which can be inactivated by moist heat treatments, drying, soaking and cooking like unit operations. *Dioscorea* yams require minimum inputs to produce large amount of edible materials and also processing and preserving of these yams are also not hard. Therefore, they are a good option to overcome the food scarcity in the world.

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