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Current perspectives on the Nutrient composition and health benefits of yams (*Discorea* species)

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Abstract

Yams (*Discorea* spp) are food security crops which serve as invaluable food sources of energy, micronutrients and phytochemicals with numerous health benefits. They show a lot of genetic and compositional diversity. New biologically active compounds are being identified from wild yams. This review focuses on the nutrients, and phytochemicals found in yam species and their health benefits. The B group of vitamins, vitamin C, pro-vitamin A; copper; manganese; isoflavones; steroidal saponins; alkaloids; terpenes; and anthocyanidins are found in different species of yams. Wild yams such as *Discorea villosa* and *Discorea hispida* are used in ethnomedicine because of their phytochemical content. Diosgenin, dioscorin, dioscin dihydrodiscorine protodioscin, methyprotodioscin, prosapogenin, epifzelechin, glucopyranoside, phytoestrogen and allantoin are bioactive phytochemicals that may be found in yams. They are valuable as anti-cancer, anti-mutagenic, anti-inflammatory, anti-diabetic, anti-ageing lipid lowering and hepatoprotective agents. Other claims based on traditional uses of yams have not been scientifically substantiated. *Dioscorea* species are likely to contain other unidentified secondary metabolites. *Discorea* species with other health promoting bioactive compounds should be identified; modern techniques should be used to extract yet unidentified compounds in *Discorea* and the food use and health benefits of yam species should be optimized.

Keywords: Yams, Composition, Nutrients, Phytochemicals, Health benefits

Introduction

Yams

Yam is a basic food that is well consumed in the tropical and humid regions of South America, Africa, and South- east Asia (Achi, 2000; Sanusi and Salimonu, 2006; Chukwu, et al., 2007). It is a staple food in many parts of West Africa and contributes significantly to food security in the region (Kouakou, 2010; Amanze et al., 2011). It is cultivated in Africa (West Africa; parts of East, Central and South Africa), Southern Asia (China, Japan and Ocenia), the Caribbean (Mexico and parts of Central America) (FAO, 2008; Polycarp et al., 2012). Yams are used as carbohydrate staples in parts of Africa and Asia (Barton, 2014). Nigeria is a major producer of yams accounting for up to 70% of the global production. *Discorea rotundata*, *Discorea esculenta*, *Discorea cayenensis* and *Discorea alata* are the most widely cultivated species. The yam most commonly bought and consumed in first world nations is White Yam (*Dioscorea rotundata)* followed by Purple Yam (*Dioscorea alata)*.

Diversity of yam species

Yam tubers are native to Africa and Asia: Nigeria, Ghana, Ivory coast, Benin, Ethiopia, Togo,Cameroon,Central African Republic, Chad and Cuba. Yams have genetically diverse species. A lot of research efforts have been geared towards the selection of important species from a variety of wild

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and domesticated species for improved nutrition and health. Obidiegwu and Akpabio (2017) investigated the geography of yam cultivation in Southern Nigeria, while Okoye et al. (2013) investigated the yam consumption patterns in West Africa. Barton (2014) documented the origin and development of yam species. Tando et al. (2015) and Muthania et al. (2013) observed the genetic diversity of Kenyan wild yams; Oben *et* al. (2016) explored the diversity of Cameroonian yams, while Debnath (2019) explored *D. alata* genotypes for better cultivation in India. Mignounia et al. (2002), investigated the isozymic diversity of *D. rotundata* and *D. cayenensis* in Cameroon. Fanyi et al. (2019) even investigated the diversity in the polysaccharides of *D. opposita* genotypes. These genetic diversities also imply variable nutrient and phytochemical composition (Wu et al., 2016). Table 1 summarizes the various yam species and their areas of production.

Table 1. Yam Species Common names and Areas of Production

Common Name	Scientific Name	Area of Production
White yam/White Guinea yam	*Discorea rotundata*	West Africa
Yellow yam/Yellow guinea yam/ Sand paper	*Discorea cayenensis*	Africa: West Africa: West Indies
Trifoliate yam/ African bitter yam	*Discorea dumetorum*	Africa
Water yam/Greater yam/Asiatic yam/purple yam/winged yam	*Discorea alata*	Found in Southeast Asia
Chinese yam/Lesser yam/bitter yam	*Discorea esculenta*	Found in Thailand, China, Southeast Asia,Western Pacific Islands,India, Norhern Australia
Aerial yam/potato yam/Air potato	*Discorea bulbifera*	Grows wild in Africa and Asia: Cultivated in South America: the Carrabean and parts of Southern US.
Asiatic bitter yam	*Discorea hispida*	Asia
Cinnammon yam	*Discorea opposita/Discorea batatas*	Cultivated in China, japan, Korea, Taiwan
Cush-cush yam/Indian yam/Yampee/ Mapuay/Inhame/Tabena	*Discorea trifida*	Northern South America; the caribbean.
Globe yam	*Discorea globosa*	India
Japanese yam/yamatoima/mountain potato	*Discorea japonica*	Japan
Wild yam	*Discorea villosa; D alata; D. batatas; D. composita; D. floribunda; D. hirticaulis; D.japonica, D. macrostachya; D. mexicana, D.opposita; D. tepinapensis,*	China, Korea, Japan India, North America, Canada, Latin America

Varieties of Yams

Although there are many yam varieties, white yam (*Dioscorea rotundata Poir*), is the most favoured yam species in West Africa because of its colour and its highly viscous starch. It is used in pounded yam preparation (which is one of the most popular and prestigious foods of West Africans) (Mozie and Okoro, 1990; Nweke, 2016). It is very palatable and a highly valued crop, worldwide (IITA, 2004). In 2019, 96.5% of global yam production was from Africa; 2.4% from the Americas; 0.7% from the Oceania and 0.4% from Asia (FAOSTAT, 2020). Nigeria is the largest producer from West Africa (>30 million tonnes) followed by Cote d'Ivoire; Ghana and Benin (with about less than 5 million tonnes each) (FAOSTAT, 2020). By 2012, world production of yams was 58.75 million tons and Nigeria produced 38 million tonnes (Verter and Becvarova, 2015). For a long time, yams have provided food for many of the world's poorest and undernourished households, and is generally valued for its numerous varieties and stable yields under conditions in which other crops may fail (Scott *et al.*, 2000).

In Nigeria, many farmers cultivate only white yam. Others cultivate white yam and other yam varieties. *D.rotundata and D. cayenensis* have been used as baseline collections for developing new hybrids. *D.esculenta* does not store as long as other yam species. It does not also contain discorine which is found in other yam species. Japanese yam (mountain potato) contains a large amount of diastase which helps digestion. The term wild yam is used for many wild species. *Dioscorea villosa* is a tuber vegetable, commonly referred to as 'Wild Yam'. In ethno medicine, it is recommended for menopausal and menstrual symptoms. 'Wild Yam' also used to refer to many other species such as *deltoidea*, *versicolor*, *bulbifera*, and *triphylla* (Bhandari *et al*., 2003; Bhandari and Kwabata, 2004a, 2004b, 2005).

Traditional uses of yams

There are many traditional uses of yam tubers and different methods of preparation. Yam tubers have rough skin (which may be light pink to dark brown). Traditionally yams are used for food and for diverse health problems. 'Fufu' or 'pounded yam', is an African dish, prepared using yam (Nweke, 2016). The powder of Chinese yam is used to make a cake-like mass which is taken with soup, sauce or stew (Zhang et al., 2014). Yams may be eaten boiled, fried or roasted; alone or in combination with legumes, and other foods. In the humid tropical countries of West Africa, yams are one of the most highly regarded foods. In Nigeria, yams have important socioeconomic, cultural and religious functions. Yams are presented during traditional marriages, cultural festivals, burials and religious outings. They are used for traditional ceremonies, indicating the high status given to the food crop. Annual yam festivals are celebrated. In the traditional settings, yams also have a lot of ethno pharmacological applications (Kumar et al., 2017)

Nutrient Composition of Yams.

The composition of yam tubers vary. Yams are very good sources of carbohydrates, the B group of vitamins and Viamin C (Ojo and Ojo, 2009). The USDA estimates of the nutrient composition of yam compared with the nutrient content of *D. opposita* is shown in Table 2a. Many species contain phytohemicals in addition such as isoflavones, saponins (e.g. diosgenin which is a steroidal saponin), phytates, tannins, alkaloids (e.g. dihydrodiscorine), terpenes and carotenoids, isoflavones and proanthocyanidins (Bhandari and Kwabata, 2004a, 2004b; 2005).

Table 2a. USDA Nutrient Composition of Yam and nutrient composition of *Discorea opposita* (Chinese yam)

Parameter	USDA	% RDA	Chinese Yam
Carbohydrate	27.88g	21	5%
Protein	1.53g	3	3%
Fat	0.17g	0.5	0.5%
Dietary fibre	4.1g	11	11%
Minerals			
Sodium	9mg	0.5	0.5%
Potassium	816mg	17	17%
Calcium	17mg	0.5	2%
Magnesium	21mg	5	5%
Iron	0.54mg	7	7%
Vitamins			
E	0.35mg	2	2%
C	17.1mg	28.5	17.1%
K	-	-	2%
A	Beta-carotene 83ug		5%

RDA = Recommended Daily Allowance

Yam (Dioscorea spp.), raw, Nutrition value per 100 g. (Source: USDA National Nutrient data base):Wu et al., 2016

Table 2b. Proximate composition of Discorea dumetorum, Discorea alata and Discorea bulbifera

Parameters	*Discorea dumetorum*	*Discorea alata*	*Discorea bulbifera**	*Discorea hispida*
Moisture (%)	6.10-9.6	6.79	7.16-7.71	15.8-37.8
Ash (%)	2.23-3.79	2.93	2.51-3.97	0.29-1.24
Crude fat (ether extract) (%)	0.50-0.71	1.15	0.37-4.15	1.99-9.36
Crude fibre (%)	1.02-2.03	2.31	1.63-2.45	-
Protein (%)	6.74-9.12	10.27	6.82-9.62	1.13-6.20
Carbohydrates (%)	78.83-79.71	76.55	76.42-77.41	58.3-71.9

Ezeocha and Ojimelukwe, 2012. Egbuonu and Nzewi, 2016.Princewill Ogbonna and Ibeji, 2015. *Values are averages for the green , red and yellow cultivars of *D. bulbifera*.

Nature and Nutrient content of the Chinese wild yam

Dioscorea opposita is the Chinese wild yam which can be eaten raw. It is smaller than the African yam. Chinese Yam (*Dioscorea opposita*) is called "Huai shan" in China. In Korea, it is called "Seyeo" In Vietnam it is called "Khoai mai" In Japan it is called "Nagaimo". It is a swollen cylindrically shaped rhizome which functions as a storage organ that holds nutrient for the plant. The vine of this plant is almost 3 meters long. A thin outer skin covers the white flesh. The fresh yam has a crispy texture and gives out a slippery mucous like substance similar to ladyfingers. The dried flour from the yam has a powdery texture. It has a taste which is mildly similar to that of potato. The yam is presently grown in China, Korea and Japan. Its nutrients are quite different from many other yams and are listed in Table 2a. Its potassium, iron and dietary fibre contents are relatively high when compared with other tubers. Its carbohydrate content is lower than other yam varieties.

Comparative evaluation of yam nutrients

Table 2a,and b show the compositon of different yam species. Composition of basic nutrients vary with the yam species. Several authors have observed different values for proteins (up to 10%) for *D. alata* and as low as 1% for some varieties of *D. hispida*. Chinese yam has been identified to have up to 11% dietary fibre. It can therefore be observed that composition varies with the yams variety as well as the climatic, soil and agronomic conditions.

Processing methods also affect the proximate composition and nutrient content of yams. Fermentation for about 72 h increased the protein, fat, crude fibre and fat contents but decreased the carbohydrate content of *D. dumetorum* and *D.alata* yam species (Ezeocha and Ojimelukwe, 2012).

Carbohydrate

Yam is a good source of energy; 100 g provides 118 calories. It also contains a lot of complex carbohydrates. Yams contain more than 20% of the daily requirements for carbohydrates. Yam carbohydrates provide energy and promote good mitochondrial function. Yams are also good sources of dietary fibre (species like the Chinese yam contain good amounts of dietary fibre). Yam carbohydrates are found mainly in the form of starch. The amylose/amylopectin ratios of yam starches are higher than the ratio found in other tubers (McPherson and Jane, 1999; Wu et al., 2016). Some yam species like *D. tryphylla* and *D. versicolor* contain relatively low amounts of carbohydrates (17.4% and 25.9% respectively) (Adepoju et al., 2017). *Discorea trifida* contains 30% starch (a waxy starch that lacks amylose) (Guilois et al*.,* 2011; Perez et al*.,* 2011)**.**

Dietary fibre

Some yam species contain high amounts (up to 4.1g/100g) of dietary fibre. Dietary fiber helps reduce constipation, decrease the level of bad (LDL) cholesterol by binding to it in the intestines and lower colon; thereby reducing the risk of cancer by preventing toxic compounds in the food from adhering to the colon mucosa. Additionally, being a good source of complex carbohydrate, it regulates steady rise in blood sugar levels. For the same reason, yam is recommended as low glycemic index and healthy food (Sahu et al*.,* 2020).

Proteins

Yam proteins (about 1.53g/100g- 5.0g/100g) are rich in phenylalanine and threonine but contain only limited amounts of the sulphur containing amino acids (cysteine and methionine) and tryptophan. They are also conjugated proteins that contain phytochemicals and minerals that are essential for good health. The protein is not evenly distributed in the yam tuber. More protein is found near the peel (skin). The quantity of protein found in yams is inadequate to meet dietary needs. Staple yam diets should be supplemented with protein rich foods (Ezeabara and Anona, 2018). Dioscorin is a yam storage protein which is also a bioactive compound.

Vitamins

Different varieties of yams contain variable amounts of vitamins. Soil and environmental management practices also affect the vitamin composition of yams (Udensi et al*.,* 2008)**. Vitamins** B_1, B_3, B_5, B_6, C, E, beta-carotene, biotin, and folic acid may be found in good quantities, depending on the yam variety (Ezeocha and Ojimelukwe, 2012). The fresh root also contains good amounts of the antioxidant vitamin, vitamin-C; providing about 29% of recommended levels per 100 g. Vitamin-C plays some important roles. The vitamin C found in many yam varieties helps wound healing, strengthens/boosts the immune system, assists bone growth and is also an anti-ageing vitamin. Vitamin C helps the body to produce enough collagen to maintain the tissues of the digestive tract. It boosts the immune system and protects the body against damage by free radicals. The B vitamins help the body to make red blood cells and make energy from foods through their coenzyme functions. Vitamin B_6 supports biochemical reactions related to healthy immune functions. Vitamin B_6 (pyridoxine) is a coenzyme of amino acid metabolism. Vitamin B_{12} helps in the production of deoxyribonucleic acid (DNA), nerve cells, blood cells, as well as the maintenance of a healthy brain and immune system. It is a co-enzyme required for body detoxification reactions. This vitamin helps to maintain blood flow to the brain. Biotin and vitamin D are required for proper growth of the hair (Ojmelukwe et al., 2005).

Some yam species contain significant amounts of vitamin-A, and β-carotene (Ferede et al., 2010). Carotenes convert into vitamin A inside the body. The carotenes and vitamin A are powerful antioxidants. Vitamin A has many functions like maintaining healthy mucosa and skin, cell differentiation, night vision, growth and protection from lung and oral cavity cancers. The carotenoid rich yam varieties play a crucial role in maintaining vision (Oladeji et al., 2016). They keep the cornea clear; decrease the amount of oil that the sebaceous gland produces and promote hair growth. The pro-vitamin A found in some yam tubers maintains the mucus membranes, assists growth and differentiation, protects the oral cavity and lungs from cancers; prevents night blindness and promotes growth and development. Three genotypes of *Discorea dumetorum* species were found to contian high amounts of vitamin A carotenoids (10.13 µg g $^{-1}$ and 14.00 µg g $^{-1}$.). Trans beta–carotene–5-8-epoxide was found to be very abundant in this yam species (Oladeji *et al.,* 2016). Three cultivars of *D. bulbifera* (green yellow and red were studied by Princewill Ogbonna and Ibeji (2015) and the average values for vitamin A and vitamin C were 137.27-700.88 IU and 0.04-0.26mg/100g respectively. Discorea caynensis tubers are good sources of pro-vitamin A (Adepoju *et al.,* 2017).

Table 3. Phytochemicals found in Cultivated and wild D. dumetorum

Phytochemical	Cultivated *D dumetorum*	(%)	Wild (edible) *D. dumetorum* (%)	
Fatty acids	Lauric acid	0.56	Linoleic acid	ND
	Myristic acid	2.25	Palmitic acid	10.83
	n-pentadecylic acid	5.59		
	Palmitic acid	21.82[b]		
	cis-oleic acid	10.95		
	Linoleic acid	ND		
Phenols	3,5-Di-t-butyl phenol	1.18	3-Decanone,5-hydroxyl-1-(4-hydroxy-3-methoxyphenyl	1.47
	3,4,4,5-tetramethoxychalcone	ND	3,5-Di-t-butyl phenol	3.38
	13-hexyloxacyclotridea-10-en-2-one	ND	Dihydroxanthin	ND
Sterols	17-(1,5-Dimethylhexyl-10,13,dimethyltetradecahydro-1-H-cyclo-penta[a} phenanthren-3-ol	5.63	Cholesteryl alcohol	ND
			17-(1,5-Dimethyl hexyl-10,13-dimethyl Tetradecahydro-/H-cyclo-penta[a]phenanthren-3-ol	4.47
Aldehydes and ketones	Trans, trans-2,4-decadienal	ND	Vanillyl acetone	0.64
Alcohols	Nonadecatriene-5-14-diol	ND	9,12-Octadecadien-1-ol	
	9,12-octadecadadiene-1-ol	33.52		
	2 Furan menthol	ND		
Hydrocarbons	3-Hexadecene	ND	(1-Methyl-2-piperidinyl) methane	19.16
			Pentadec-1-ene	0.70
			1-Decyl-1-cyclo hexane	ND
Esters	2-Hydroxy-1 (hydroxymethyl)ethyl ester	6.15	2-Hydroxy-1-(hydroxymethyl) ethyl ester	
	Glycerol-1-monolinolate	ND	Methyl Linoleate	
	Beta-monoglyceride	ND	Methyl(7E)-7-Octadecenoate	
	Methyl(9E,12E)-9,12-octadecadienate	ND	Glycerol-1-monolinolate	6.39
	Pthalic acid di (1-hexen-5-yl) ester	ND	Palmitic acid beta-monoglyceride	6.07
Amines	Oleic acid amide	1.12	(2E)-2.7-Dimethyl 2,7-octadien-1 amine	4.14
	Bis (2-Dimethylaminoethyl		Oleic acid amine	1.92
Furan	5-methyl-5-(4,8,12-trimethyltridecyl) dihydro 2(3H)-furanone	ND		-
Alkaloids			Decahydro{1,7} naphthyridine	21.09

Ezeocha and Ojimelukwe, 2012. ND = Not determined.

Minerals

The yam tuber is one of the good sources of minerals such as copper, calcium, potassium, iron, manganese, magnesium, iodine, selenium, zinc and phosphorus. Zinc aids reproduction and protects cells against damage. Copper is a blood forming element and a cofactor for many metabolic reactions. Copper is essential for the production of red blood cells. Some yam species contain significant amounts of manganese (up to 17%). 100 g provides about 816 mg of potassium. Potassium is an important component of cell and body fluids which helps in controlling heart beating rate and blood pressure by countering hypertensive effects of sodium. The body uses manganese as a co-factor for the antioxidant enzyme, superoxide dismutase. Iron is required for red blood cell formation. The B-complex group of vitamins mediates many metabolic body functions. Copper and iron help in the formation of the red blood cells in the human body. Five cultivars of *Discorea hispida* were studied by Saleha et al. (2018). They were found to contain significant amounts of phosphorus (11.7-46.9mg/100g).

Phytochemical composition of some Discorea species.

In addition to nutrients, there are various phytochemicals found in different yam varieties that are beneficial to human health. The quantities of these nutrients and phytochemicals vary with the yam varieties and are influenced by agronomic factors such as soil conditions (pH, available nutrients, organic matter, moisture); the climate (including temperature, precipitation, light intensity), post-harvest handling and storage. *Discorea hispida* samples were found to contain alkanoids and terpenoids. One cultivar also contained phenols and steroids (Saleha *et al*., 2018).

The phytoestrogens help in regulating the female hormone levels. The antioxidant properties of phenolic compounds result from their redox potentials, free radical scavenging activity and singlet oxygen quenching ability (Rice-Evans *et al.*, 1997; Ukom *et al.,* 2014; Ojimelukwe et al., 2017).

Fatty acids, phenols, sterols, aldehydes, ketones, alcohols,hydrocarbons, esters, amines, furans and alkaloids were identified in cultivated and wild varieties of *Discorea dumetorum* (see Table 3). *D. dumetorum* was found to be a rich source of alkaloids (1.75%) and tannins (2.12%) (Ezeocha and Ojimelukwe, 2012).The wild species contained significant amounts of alkaloid D ecahydro-1,7 naphthyridine (21.09%). The naphthyridine derivatives exhibit diverse biological activities such as anti-inflammatory, antimicrobial, antiviral, anticancer, antihypertensive and analgesic activities (Gurjar and Pal, 2019). It also contained high amounts of hydrocarbons (1-methyl-1-2-piperidinyl) methane- 19.6%) and palmitic acid (10.83 %). The cultivated *D. dumetroum* contained large amounts of palmitic acid in their fat (20.82 %); cis oleic (10.95 %) acid as well as the alcohol; 9, 12-octadecadiene-1-ol (33.82 %).

Ethnobotanical Uses of Yams

Yams have numerous medicinal uses in different traditional settings. Its root extracts may be used in treating nephritis; tiredness, poor digestion, poor appetite, weight loss, hyperthyroidism and diabetes (Bone et al., 2000; Chandrasekara and Kumar, 2016). The tuber is used in treating ulcers and boils. The juice of the leaves is useful in treating snakebites and scorpion stings. The tuber acts as an anthelmintic element for removing parasites from the gut (BoneZava et al., 1998). The wild varieties are often associated with a lot of perceived health benefits. Wild yam may be used for the treatment of muscular pains and cramps (such as menstrual pains and premenstrual syndrome); inflammation caused by rheumatoid arthritis; treating symptoms of menopause (Carroll, 2006: Haimov-Kochman and Hochner-Celnikier, 2005; Kelley and Carroll, 2010; Komesaroff et al., 2009). It is also percieved to be useful as anticoagulant; in protecting the walls of arteries and veins; preventing localized abdominal cramps; promoting the secretion of bile; purifying and detoxifying the body; controling afterbirth pain; preventing diverticulosis; controlling hyperlipidaema; managing cough; preventing morning sickness, infertility,osteoporosis, nausea, gall bladder problems; mood swings and retarding the ageing process (Kumar et al., 2017). *Discorea opposita* and *Discorea villosa* have been used as medicine in Asia and beyond. A cream containing 22% and 33% (respectively) of *Dioscorea villosa* decreased diurnal and non-flushing symptoms but was not significantly different than placebo. However, the cream (10% *Dioscorea villosa*) also contained *Linum usitatissmum*, *Perlargonium graveolens*, and *Salvia officinalis* with 10mg active Vitamin E, suggesting that the observed effects should not be attributed to *D. villosa* alone (Kaimel and Kemper, 2009). *Dioscorea villosa, D. opposita, D. hypoglauca, D. composata, D. deltoida, D.parazeri, D. mastrostachya, D. floribunda, D. barbasco, D. macrostachya* and *D barbasco* are considered as medicinal species of yams (Kaimel and Kemper, 2009)

Health benefits of some yam varieties

Discorea villosa is a medicinal yam with a lot of perceived health benefits. Many pharmacologically active compounds have been found in it (Manda et al., 2013; Aumsuwan et al., 2016)). Three furostanol saponins, parvifloside (27.3 mg), methyl protodeltonin (67.1 mg) and trigofoenoside A-1 (18.5 mg) were extracted from *D. villosa* with n-butanol and isolated through metabolomics mining. Further identification of the compounds in the spirostanol-rich extract deciphered four spirostanol saponins: deltonin (31.5 mg), dioscin (7.7 mg) zingiberensis saponin I (15.2 mg) and prosapogenin A of dioscin (3.4 mg). Other biologically active compounds found in *Discorea villosa* are protodioscin, methyprotodioscin, prosapogenin, epifzelechin, glucopyranoside and phytoestrogen.

Anticancer effects of D. villosa

Screening of a large number (more than 300) medicinal herbs, seeds, roots, plankton and fungi for their antitumor effects showed that *Dioscorea villosa* was the most effective product, in inducing apoptosis in the tested tumor cell line. In a neuroblastoma cell line (Neuro-2a), *Dioscorea villosa* ethanoic extract showed an LD_{50} of 19mcg/mL, suggesting that *Dioscorea villosa* may confer anti-cancer effects (Ali *et al*., 2013), but scientific evidence on efficacy and safety are limited (Aumsuwan et al., 2015; 2016). Research to determine other bioactive compounds is still on-going. Diarylheptanoids with diverse pharmacological activities have been found in this yam variety (Dong et al., 2012). .

Management of Type 2 Diabetes

Some yam varieties have been found useful in the management of type 2 diabetes. Adebayo et al. (2012) found that *Discorea* spp modulated the levels and functions of two key enzymes associated with type 2 diabetes in vitro. *D.rotundata* and *D.alata* flours were found to inhibit alpha amylase and alpha glucosidase (key enzymes linked to type 2 diabetes) in a dose dependent manner (1-4mgL^{-1}) (Adedayo et al., 2012). Processing of the yams significantly reduced their inhibitory activities. *D. dumetorum* also has anti-diabetic effect (Undie and Akubue, 1986). Mc Anuff et al. (2003), observed that the Jamaican bitter yam (*D. polygonoides*) steroidal sapogenin extract improved the intestinal morphology of streptozotocin induced diabetic rats thereby improving digestion. Go et al. (2015) was able to establish the antidiabetic effect of *Discorea batatas* in a rat model of streptozotocin –induced diabetic rats. This yam species as well as allantoin which is one of its bioactive constituents modulated the antioxidant activities and lipid profiles by promoting the release of glucagon-like-peptide-1 (GLP-1), thereby improving the functions of the beta cells to maintain normal insulin and glucose levels Rawat and Palmer, 2013).

Management of Oxidative stress and Hyperlipidaemia

Some researchers have observed the beneficial effect of some yam species on oxidative stress (Boban et al*.,* 2006). The yam phenols were associated with their antioxidant activities (Ukom et al*.,* 2014). The *Discorea* rhizome was found to reduce oxidative stress and artherosclerosis in hyperlipidaemic rabbits (Chang *et al.,* 2005). Son et al. (2007) also observed that diosgenin (a steroidal saponin found in Discorea species) exhibited antioxidative and hypolipidaemic effects on rats fed high amounts of cholesterol. Miyazawa et al. (1996) reported the presence of paneol in *Discorea jopponia* which showed anti-mutagenic activity

Some Bioactive compounds/derivatives found in yams and their health benefits

Yams contain biologically active substances, such as diosgenin, dioscin, other steroidal saponins, dehydroapiandrosterone (DHEA) and discoretine (see Table 4). Many wild yam species with significant amounts of the bioactive compounds are bitter.

Biological functions of yam phytochemicals

Table 4. Biological Functions of Phytochemicals found in Yams

Name of Phytochemical	Nature/Mode of action	Yam species	References
Diosgenin	A hydrolysis product of saponins; accelerates keratin protein synthesis to retard skin ageing. Manages cholesterol level; improves lipid profiles and modulates oxidative stress; may be used for the commercial synthesis of cortisone,pregnelonone, progesterone and other steroids; believed to improve gastrointestinal;sensory and sexual functions;influences the secretion of bile.	*D. opposita; D. japponia; D.bulbifera; D.vesicolor;D.deltoidea; D. triphylla*	Lin and Yang, 2008. McLeedy and Chynes, 2001; Teda et al., 2009; Lin et al., 2006; Accatino et al., 1998; Dong et al., 2018
Dioscin (Diosgenin glycone)	Anti-inflammatory, especially for situations related to rheumatoid arthritis; lipid lowering activity; anti tumor activity; regulates blood sugar; has antifungal activity; has membrane disruptive activity	*D. alata; D. opposita; D. persimilis; D. fordii. D. nipponica*	McAnuff et al., 2003; Chang et al., 2005;Manda et al., 2013
Alkaloids (e.g. dihydrodiscorine)	Affects the central nervous system. Used as fish poison.		
Terpenoids			
Phenols		*D. bulbifera; D. versicolor; D. triphylla*	Patel et al., 2015
Saponin	interferes with DNA replication and prevent the multiplication of cancer cells, binds cholesterol		
Dioscorin	dioscorin-(yam protein that has antioxidant & hypoglycaemic properties).	*D. hispida*	Kumoro and Harati, 2015; Hou et al., 2001
Proanthocyanidin	binds physically to cell walls and prevent the adhension of pathogens to human cells)		
Purine degradation product (e.g. Allantoin)	Allantoin improves the secretion and function of glucagon	*D. alata; D. opposita; D. persimilis; D. fordii;* D. batatas	Chandrasekara and Kumar, 2016; Go et al. (2015)

Diosgenin

One major bioactive component of yams is diosgenin, and a variety of molecules which are diosgenin bound to different glycosides. It is commonly found in wild yams. Diosgenin is considered the most important bioactive compound in yam and it is an aglycone. It is a steroid hormone precursor in–vitro. Diosgenin may be used commercially for the synthesis of cortisone, pregnelonone, progesterone and other steroids. Diosgenin enhances DNA synthesis in human 3D skin model and also increases the uptake of bromodeoxyuridine (Meleandy and Clynes, 2001). It interacts with estradiol which is a natural hormone and a precursor for estrogen. It can be used for controlling hyperlipidemia, hyperglycemia, and cardiovascular diseases. It even has immunomodulatory

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and antitumor functions. Diosgenin has been found to possess anti-ageing effect. In experiments with a human 3D skin equivalent model (TESTSKIN cells), Diosgenin was found to enhance DNA synthesis in a similar manner as retinoic acid (active form of Vitamin A) at 10nM in human keratinocytes. The action of diosgenin was through a cAMP dependent pathway (which was blocked by an inhibitor of adenyl cyclase) that is independent of both estrogen receptors and GPR30 (Manda et al., 2013). When Diosgenin was administered to ovariectomized mice at 0.01-0.04% of the diet for 20 weeks, the mice had improved skin thickness. Diosgenin is structurally similar to estradiol; the active form of estrogen in the human body. Estrogen in the human body is found in three major forms: estradiol, estrone and estriol. In the liver and small intestines, estrone is converted to estradiol. Its concentration (i.e estradiol) increases after menopause, when the adrenal glands play more pronounced role in hormone synthesis than the ovaries. Estrone and estradiol are metabolized to estriol; their primary urinary product (Lippert et al., 2003). It was also found to induce differentiation of leukemia cells (Ghezali et al., 2014). The status of diosgenin as a phytoestrogen has not been ascertained as it does not interact with estrogen receptors. Wild yam is also rich in saponins and alkaloids. Antioxidant and hypolipidaemic effect; anticancer; interacts with estradiol; influences bile secretion.

Dioscin

Dioscin is a naturally occurring steroidal saponin found in wild yams. Dioscin possesses numerous pharmacological effects. It demonstrates cytotoxic effects through the induction of apoptosis (Cai et al., 2002; Qu et al., 2014)). It has antitumor and antifungal effects (Liu et al., 2012; Choi et al., 2013). It inhibits bone re-sorption and osteoclast differentiation functions (Qu et al., 2014). It has anti-inflammatory, lipid-lowering, and hepatoprotective effects (Guo et al., 2016). It is may be used for the synthesis of diosgenin and other steroidal drugs (Perez et al., 2011). It has also been found to possess nephroprotective, antiviral and cardio protective effects (Yang et al., 2019).

Discoretine

Discoretine is a bioactive compound associated with the effective management of diabetes and is useful for regulating blood sugar. The methanolic extract of *D. dumetorum* showed hypoglycaemic effect in healthy and alloxan diabetic rats when administered intraperitoneally (ip) at 20mg/kg. (Iwu et al., 1990). Discoretine is found in good quantities in *D. villosa.*

Dioscorin

Dioscorin is the major protein found in yam tubers. It can be extracted with water and accounts for about 90% of the extractable proteins in yams. It functions as an alkaloid and possess trypsin inhibitor and immunomodulatory activities. It also has antihypertensive and antioxidant properties (Harijono et al., 2013). It is found in *D. opposita, D. esculenta D. alata, D. japonica,* and *D. batatas.*

Dihydrodiscorine

Dihydrodiscorine is a toxic alkaloid found in some raw yams which has found application as fish poison. Some species of *D. dumetorum* contain dihydrodiscorine isoclines, a heart stimulant (Bevan and Hirst, 1985)

Allantoin

Allantoin has been found to regulate the secretion and function of glucagon**.** Allantoin soothes and protects the skin. It has the ability to heal the skin and stimulate the growth of new tissue. It influences the secretion of glucagon. It promotes wound healing, speeds up cell regeneration, and exhibits a keratolytic effect. It is found in *Discorea opposita*. It may also be found also in *D. alata* and *D. batatas*. Allantoin modulates antioxidant activities by promoting the release of glucagon-like peptide-1 (GLP-1), thereby improving the functions of beta cells of the pancreas to maintain normal insulin and glucose levels (Chandrasekara and Kumar, 2016).

Dehydroepiandrosterone (DHEA)

Dehydroepiandrosterone (DHEA) is a 19 carbon lipophilic endogenous steroid hormone, naturally made by the body through the cholesterol-pregnenolone pathway. It is produced by the adrenal glands, the gonads, and the brain. It improves the well-being of females and enhances the pituitary function of males with impaired pituitary function. It affects the thyroid hormone status thereby affecting the energy balance by increasing metabolic rate and decreasing fat stores. It is related to diosgenin because it is one of the important bioactive compounds that can be made from diosgenin. It can also be synthesized from other sources like geniestein, wild yam, soy and cholesterol. It is believed to be found in some species of Mexican yams. It serves as an indirect precursor to estrogen and testosterone and other steroid hormones. The natural production of this hormone progressively declines at the rate of 2% per year as an individual gets older. It is not clear, whether intake from supplements influences the body levels of the hormone. DHEA is associated with a large variety of pharmacological activities like antidiabetic, anticancer, anti-allergic, control of osteoporosis; control of dementia; anti-ageing; obesity reduction and cardiovascular effects. It is beneficial in autoimmune disorders like lupus erythematosus, immune modulation, muscle building and hormonal problems. Plain DHEA has a breakdown product 7-keto DHEA, which can also be produced from diosgenin (Park et al., 2009). 7-keto DHEA enhances immune function and reduces body fat. Its efficacy is double that of DHEA. DHEA can be converted to testosterone and estrogen, while 7-keto DHEA cannot be converted to these sex hormones.

Other Saponins

Other saponin extracts from wild yams may be used as an anticoagulant and a diuretic for managing inflammation due to rheumatoid arthritis. It is also used to manage muscle pains and cramps. *D hispida* contains significant amounts of saponins. Other perceived health benefits of wild yams are prevention of vaginal dryness in older women, management of pre-menstrual symptoms and menstrual cramps, management of osteoporosis; increasing sexual drive , diverticulosis and gall bladder pain (Taylor, 1997).

Side Effects, Safe Dosage and Toxicity of yams

The cultivated yam species are not associated with any toxicity symptoms. Wild yam is considered safe for consumption by most people, when taken in small quantities.

However, eating large amounts may cause side effects like headaches, nausea, vomiting and digestive disorders. Safe dosage of wild yam depends on person's age and health conditions. Generally people supplement with 425mg wild yam root twice daily, though further studies are needed (Foster, 2000). Aqueous, methanol, and ethyl acetate fractions of *D. villosa* showed a fibrotic effect on the kidneys of experimental animals. They were toxic to renal tubular epithelial cells (NRK52E), suggesting that long term intake can result in fibrosis of the kidney. Feeding rats a diet of 0.72% *Dioscorea villosa* over a period of 28 days, caused mild renal tubulo-interstitial fibrosis although no macroscopic changes were observed. Macrophages were found to accumulate in the glomeruli and interstitial spaces of the liver. Dihydrodiscorine is a toxic alkaloid found in some raw yams which has found application as a fish poison. In animal studies to investigate safety with consumption of *Dioscorea villosa,* no harm was observed after the consumption of 500mg/kg of *D. villosa*, but the oral dose of 2000mg/kg was able to induce hypo activity, piloerection and dyspnoea.

Conclusion

There is a great diversity of yam varieties and although only a few are used for food, many wild varieties are used as medicines in different traditional settings; because of their perceived health benefits. This diversity (and the fact that novel compounds are presently being elucidated from some varieties) suggest that there are unexplored varieties with bioactive compounds, whose metabolic functions are yet to be elucidated. The nutrients and bioactive compounds in yams are responsible for their anticancer, mutagenic; hypolipidaemic; antidiabetic; antioxidant and anti-ageing properties. Studies should be conducted to establish these claims in humans. The traditional use of yams as sex hormone precursor is yet to have scientific backing because diosgenin which is a natural steroidal saponin in yams can only be converted to other compounds (Dehydroapiandrosterone-DHEA; 7 keto DHEA) with this attribute in vitro. This review presents the existing knowledge about the composition and health benefits of yams. Specific bioactive compounds in yams have been directly linked to their health benefits. It highlights the knowledge gaps for adding value to this very important food product for improved food and nutrition security. Other perceived health claims should be scientifically established or debunked.

Compliance with Ethical Standards

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal.

All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

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