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Review Article

A Review of Yam Tuber Cultivars: Genetic Properties, Phytochemicals, Processing, Preservation and Nutritional Value

Ehoche Edache Elijah[1], Chijioke Madu[2]*, Adejoh Johnson[2], Parth K Patel[3], Garba Usman Kurmi[4]
[1]Department of Biochemistry, Federal University of Technology, Minna-920102, Nigeria
[2]Department of Medical Biochemistry, University of Abuja-900105, Abuja
[3]H. K. College of Pharmacy, Jogeshwari (W), Mumbai-400102, Maharashtra, India
[4]Department of Biochemistry, Faculty of Science, University of Maiduguri-600230, Maiduguri Borno state Nigeria

***Corresponding Author**
Chijioke Madu

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Abstract: Yam is a very essential tuber stem with relevance to nutrition, medicine and others. In this review, common cultivars of yam were discussed in respect to genetic indicators, modifications, development and evaluation of molecular markers, genetic improvement of yam, hybridization and selection of cultivars. Other important areas reviewed from different articles include genetic tools for yam improvement, properties of yam cultivars, phytochemicals of yam, phytochemicals interactions with edibility of yam as well as nutritional value of yam, processing methods and biological implications, effects of processing methods on the nutrient and anti-nutrient composition of yam; and the storage techniques practiced in yam farming. Information from this review will enable scientists, government agencies, policy makers amongst others to make quality decisions as it relates to yam and food availability towards achieving the United Nations sustainable development goals.

Keywords: Cultivars, Genetics, Nutrients, Processing, Yam.

INTRODUCTION

Yam (Dioscorea species) is one of the most consumed staple stem starchy tuber in most part of the developing world. These regions with the highest food crises include: Africa, South America, Asia, the Caribbean, parts of Europe and Oceania.It has been attributed as the world's fourth most economical tuber [1]. Nigeria is the most important yam producing country worldwide [2].

The Discorea genus contains more than 600 species, of which only a few are cultivated and consumed as a major source of carbohydrates. Nutritionally, yam tuber also contains appreciable amounts of proteins, vitamins and minerals [3, 4]; as well as important photochemical of pharmaceutical and industrial potentials.

In Africa, most especially, yam consumption significantly contributes to the local economies as well as in alleviating poverty [5]. It is usually eaten after roasting, boiling, pounding, frying or converted to flour for consumption as paste [4].

Yam has been underutilized and its importance mainly is for food security. This has led to a number of breeding programmes targeted to only certain species. However an extensive exploration on the wholesome knowledge on the collective properties, potentials, processing and innovation can enhance its proper utilization beyond food security to medicine and industrial while avoiding wastage [6]. Therefore this review leads the reader through various aspects of yam tubers such as its phytochemicals, genetic properties, different techniques for preservation, processing and exploring the plethora of nutritional values, thereby aiming to create an awareness of this underutilized tuber which is one of the nature's gift to mankind.

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COMMON CULTIVARS OF YAM

Dioscorea rotundata and *Dioscorea cayennesis*

They are native to Africa and they are the mostly cultivated yam. They are considered as two separate species, but taxonomist now regards them as the same species. White yam tuber is roughly cylindrical in shape, the skin is smooth and brown,the flesh is usually white and firm. (fig1.a) the yellow color of *Dioscorea cayenensis*is as a result of the presence of β-carotene [7]. It is similar to white yam in outer appearance its tuber skin is usually a bit firmer and less extensively grooved. In Africa this yams are pounded into a paste to make a traditional dish called pounded yam [8]. *Dioscorea rotundata*and *D.cayenensis* (both knownasGuineayam) are the most popular and economically important yams in West and CentralAfrica, where they are indigenous [9-11].

Dioscorea alata

Dioscorea alata is known as the water yam or winged yam. *Dioscoreaalata*, is of two types the white species and the purple species. The white species is prevalent in the African region including Nigeria (fig1.d), and Ghana while the purple species is popular in the Asian region such as Philippine, Vietnam, and Indonesia (fig1.c). The purple color of the purple species is due to the presence of anthocyanins which is used as a natural food colorant [12]. Extracts of the purple specie have been employed in China traditional medicine and recent scientific evidences have shown numerous bioactivities including antioxidant, antidiabetic, antiosteoporotic, anti-ulcer, anti-inflammatory and hepatoprotective activities [13].

Dioscorea polystachya

It is a native yam in china; it is smaller than the African yam. (fig1.e) It is tolerant to frost and can be grown in cooler conditions than other yams. The tubers are harvested after about 6months of growth. Some are eaten right after harvesting and some are used as ingredients for other dishes including noodles and for traditional medicines [8].

Dioscorea bulbifera

The air potato is found in both Africa and Asia with slight difference between those found in each place. Some varieties of this yam can be eaten raw while some require soaking or boiling for detoxification before eating (fig1.f). It is not grown commercially since the flavor of other yams is preferred by most people. However, it is popular in home vegetable garden because it produces a crop after four months of growth and continues producing for the life of the vine as long as two years.

Dioscorea esculenta

It is one of the lesser yam species cultivated. It is cultivated very little in other parts of the world. The tubers are fairly small in most varieties, the tubers are eaten baked boiled or fried much like potato (fig1.b). Because of the small size of the tubers, mechanical cultivation is possible, along with its easy preparation and good flavor could help lesser yam to become more popular in the future [8].

Dioscorea dumetorum

The bitter yam is popular as a vegetable in some parts of West Africa possibly because its cultivation requires less labor than other yams. However, the wild forms of this yam are very toxic (fig1.g). In the south-western Nigeria, bitter yam serves as food of choice for the diabetic patients and as herb for the treatment of various ailments [14]. Likewise, the potential use of bitter yam extract as an effective hypoglycaemic agent, with hypolipidaemic and hypocholesterolaemic properties for the treatment of diabetes mellitus [15] as well as malaria treatment have been reported [16].

Dioscorea Trifida

The crush yam is native to Guyana region of South America and the most important cultivated new world yam. Because of their relative ease of cultivation and the good flavor are considered to have a great potential to increased production [8].

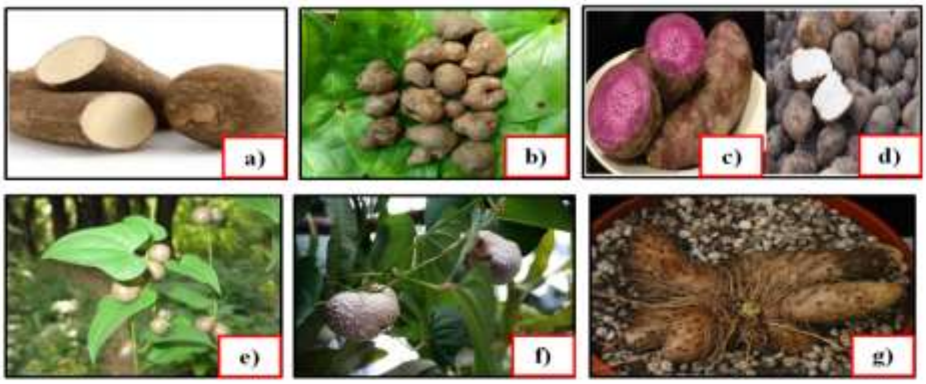

Fig-1: Varieties of yam- a) *Dioscorea rotundata*, b) *Dioscorea esculenta*, c)purple variety of *Dioscorea alata*, d) white variety of *Dioscorea alata*, e) *Dioscorea polystachya*, f) *Dioscorea bulbifera*, g) *Dioscorea dumetorum*

Genetic indicators and modification of yam cultivars

Yam is cultivated in widely varying agro ecological zones. In Nigeria, for instance the crop is grown from the southern humid forest to the northern guinea savanna. The advent of molecular markers, genome studies and plant genetic transformation has opened avenues for circumventing breeding obstacles in ling growth cycle and heterozygous crop like yam. In spite of these opportunities to build on the success in classical breeding huge challenges had to be overcome before yam scientist could develop modern technologies towards assisting breeding programs to boost yam production and keep up with the ever increasing demand.

Development and evaluation of molecular markers

Breeding and selection of yam cultivars with novel characteristics currently suffers from the fact that traditional cultivars have not been adequately characterized [17]. This seriously hampers the reliable identification of cultivars for germplasm management and improvement. System of classification is based on morphological character identification [1, 3, 5]. Sluber tuber protein profiles [18] or isozyme patterns [5, 19] have been used to characterize yam germplasm. The initial effort in yam genomics was devoted to the development of polymorphic DNA markers and assessment of their potential application in yams. However, the use of this type of DNA sequence for generating large data sets needed to populate genetic maps is not cost efficient, so the approach of using uncharacterized DNA sequences was adopted as a source of genetic markers. RAPD and AFLP polymorphism were high among diverse yam species, with AFLP revealing the highest polymorphism. A total of 64 AFLP primer combinations were tested for their potential use in assessment of genetic diversity in white Guinea yam [20]. Over 1000 polymorphic AFLP markers were identified using the 64-primer pairs. Although RAPD markers were adequate for genetic diversity studies [5], the level of polymorphism detected in mapping populations was low; RAPD was, therefore, not considered a good marker-system for mapping purposes. Contrary to RAPDs, the high level of polymorphism revealed by AFLP markers coupled with their robustness made AFLP a more reliable and reproducible marker-system both for yam genome analysis and mapping purposes.

Genetic improvement of yam

The breeding programs in many countries focus on a few Dioscorea species. The primary focus of yam breeding is the development and deployment of robust varieties with unique combination of preferred traits required for production and consumption. The programme generally target traits related to increasing intrinsic tuber yield potential as well as increasing tolerance for and resistance to yield limiting and quality reducing factors [20]. The breeding targets have been gradually adding new traits along with the primary focus on high and stable tuber yield, higher dry matter resistance to economically significant diseases (e.g anthracnose, viruses, tuber rots), pests (e.g nematodes), tuber characteristics cherished by consumers (e.g size shape and culinary quality) and plant architecture (e.g dwarf genes) that reduces the need for staking [17, 20]. The breeding efforts over the last five decades have resulted in the identification of trait progenitors and commercial release of improved cultivars. However, the local farmers' varieties are still the leading and dominant cultivars in the yam cultivation and consumption systems [21]. Transfer of genes of interest from the secondary gene pool of wild relatives to the cultivated primary gene pool is still challenging. In several crops, including yam [22, 23]. Nevertheless, the wild relatives of yam could harbor essential genes and genetic variability useful in breeding endeavors to enhance the performance of yam for various economically important traits. Yam germplasm conservation has predominantly focused on the main cultivated species with little emphasis on wild relatives. Hence, future studies can be limited if conservation efforts are not increased.

Hybridization and selection of cultivars

Yam breeding is a twostep process that utilizes both sexual and asexual reproduction. Different breeding schemes are followed by the breeding programs depending on the type of traits and targets for improvement. The general breeding outline for developing superior yam genotypes involves artificial hand or natural open pollination for the generation of full sib or half sib progenies segregating for desired traits. Subsequent selection of cloned derivatives for performance and reproducibility and stability over seasons and locations

Genetic tools for yam improvement

The genomes of many important crops have been sequenced with the advent of next-generation DNA sequencing technologies. It is particularly valuable for understanding the underlying genetics of complex traits in plants for their subsequent manipulation in crop improvement programmes. DNA sequence information is extremely relevant in identifying key genes regulating important agronomic characters and for detecting genetic variability among cultivars [24, 25]. Advances in genome sequencing through next generation sequencing (NGS) technologies have made it possible to generate millions of novel markers and high-density genetic maps. The availability of the reference genome sequence of a species also helps to replace the conventional quantitative trait loci (QTL) mapping with association mapping. Quantitative trait loci mapping offers a wide genome range within which the gene is located while association maps mark traits with high resolution [25]. Tamiru *et al.* [26] have developed and released the reference genome sequence of D. rotundata accession TDr96_F1 with a genome size of 594 Mb, out of which 76.4% is distributed among 21 linkage groups. The D. rotundata reference genome is available at http://genome-e.ibrc.or.jp/home/bioin forma tics-team/yam.

Similarly, Bredeson *et al.* [27] have also developed and released an early draft assembly of the second most important species, D. alata reference genome (https ://www.ncbi.nlm.nih.gov/nucco re/CZHE000000 00.2). The breeding line TDa95/00328 was used as the reference accession for D. alata. This sequence accounts for nearly 50% of the total genome but an estimated 80%–90% of protein-coding loci while long-read PacBio sequencing of the reference accession is currently ongoing along with the development of a dense genetic map from eight map-crosses [27]. The development and release of the reference genome sequences of the two most economically important species of yam have opened a new avenue for exploitation and in-depth understanding of the genetics, genomics and domestication of this crop [28].These data also facilitate the detection of allelic variations and candidate genes modulating key agronomic and quality traits, which is essential for the success of yam breeding.

Molecular Maker

Molecular markers are relevant tools for applications such as assessing genetic diversity and phylogenetic relationships, cultivar identification, mapping of major effect genes and QTLs, estimating population structure, identification of elite genotypes in crop improvement programmes, and for validation of progenies emanating from genetic hybridizations [29]. Many marker systems have been developed and routinely applied to yam improvement activities. Some of these marker systems applied in yam are listed below. Isozyme marker. Isozymes were the first molecular markers to be established which showed Mendelian inheritance, co-dominant expression, complete penetrance and non-existence of pleiotropic and epistatic interactions [30]. The potential of isozyme markers for molecular characterization within and between various Dioscorea species has been well established. Restriction fragment length polymorphism Terauchi *et al.* [31] exploited heterologous DNA sequences as a source of RFLP markers and developed the first RFLP markers for yam.

Amplified Fragment Length Polymorphism (Aflp)

Markers were successfully used to study the phylogeny and origin of Guinea yam [31] and genetic diversity of D. bulbifera accessions originating from Asia and Africa [32]. Amplified fragment length polymorphism markers were successfully used to explore the genetic variation of D. alata, D. rotundata,D. bulbifera, D. dumetorum, D. pentaphylla, D. cayenensis, D. abyssinica, D. esculenta, D. nummularia, D. persimilis, D. trifida and D. transversa. The comparative evaluation of three molecular marker systems (RAPD, AFLP and SSR) for characterization of D. rotundata revealed that AFLPs had the highest efficiency in discovering polymorphism and detected genetic relationships very similar to morphological classification [9]. Scarcelli *et al.* [33] tudied the practice of ennoblement of D. cayenensis, D. rotundata, D. abyssinica and D. praehensilis by farmers in Benin Republic using 91 AFLP markers. Their study established that farmers generated new cultivars with novel genetic combinations through sexual hybridization of wild and cultivated yam.

Simple Sequence Repeats

Microsatellites or SSR, due to their co-dominant nature, high level of polymorphism, high abundance and even distribution across the genome were necessary as yam genomics progressed. Terauchi and Konuma [34] detected microsatellite polymorphisms in a natural population of D. tokoro. Even though the D. tokoro microsatellite primers failed to amplify any DNA when applied to other Dioscorea species, the study revealed the potential usefulness of these markers in yam. Further advancements in yam genomics resulted in the development of 10 SSR markers in D. japonica [35]. Tostain *et al.* [36] generated and characterized 16 microsatellite markers in different Dioscorea species (D. alata, D. abyssinica and D. praehensilis) and discovered that many of the markers were transferable to other Dioscorea species in the Enantiophyllum section. Siqueira *et al.* [37] developed 14 polymorphic SSR markers for D. alata by means of a microsatellite- enriched genomic library methodology. Additionally, six microsatellite markers with high cross-species amplification involving five Dioscorea species (D. alata, D. cayenensis, D. rotundata, D. praehensilis and D. abyssinica) were developed in American yam, D. trifida [38]. Silva *et al*. [39] isolated and characterized nine SSR markers from an enriched genomic library of D. cayenensis. Tamiru *et al*. [29] developed 90 SSR markers from an enriched genomic library of D. cayenensis and found 94.4% and 56.7% of these SSRs transferable to D. rotundata and D. alata, respectively. Saski *et al*. [40] developed 1,152 EST-SSRs from EST sequences generated from two D. alata genotypes (susceptible and resistant), out of which 388 were validated as polymorphic showing a polymorphism rate of 34% when tested on two diverse parents targeted for anthracnose disease. Microsatellite markers have been utilized to investigate the genetic diversity, ploidy level, inheritance patterns and parentage analysis of various Dioscorea species

Transcriptome Sequencing

Analysis of genome-wide differential RNA expression gives researchers a better understanding of biological pathways and molecular mechanisms that control important but complex traits in plants. Narina *et al*. [41] investigated gene expression by large-scale generation of ESTs from a susceptible (TDa95/0310) and two resistant yam genotypes (TDa87/01091 and TDa95/0328) infected with the fungus C. gloeosporioides. They annotated and analyzed nearly 56% of total ESTs for functional categorization and differential expression of genes for tolerance to anthracnose disease. The assembly process generated 15,196 ESTs in TDa95/0328; 15,984 ESTs in TDa95/0310; and 13,577 ESTs in TDa87/01091 with average sequence lengths of 426, 411 and 524 bases, respectively. TDa95/0328 and TDa87/01091 had 115 and 180 unique ESTs, respectively, which could be responsible for or explain their tolerance to C. gloeosporioides. The unique ESTs of the resistant accessions were found to be related to carbohydrate metabolism, cell wall biogenesis, lipid and amino acid metabolism, secondary and hormone metabolism, transcription factors, protein synthesis, and signaling proteins as well as multiple pathogenesis-related and host defense-related genes [41]. A total of 104 candidates SNPs were also discovered between TDa95/0310 and TDa95/0328 libraries that were homologous within each genotype and useful for genotyping and developing genetic maps in yam [41]. A setback of this study is that some of the SNP markers identified are likely to be associated with broad stress or infection response and not necessarily anthracnose infection alone. Wu *et al*. [42] studied the gene expression of flavonoid (purple flesh colour) of D. alata tubers using Illumina sequencing to characterize the transcriptomes of tubers from a purple-flesh and a white flesh variety. They found 125,123 unigenes from the purple-flesh and white-flesh cDNA libraries, out of which 49.5% were elucidated in publicly accessible protein databases. Biochemical pathway analysis and functional annotation showed that 511 genes were more than two-fold differentially expressed between the purple and white fleshed yam varieties of which 223 genes were down-regulated and 288 genes up-regulated in the purple-flesh tubers. Sixty-one uni genes encoding various well-known enzymes in the flavonoid biosynthesis pathway were detected by transcriptome analysis, and their expression was further confirmed by quantitative real-time PCR (qRT-PCR) [42]. With these unigenes, 11,793 SSRs were detected and 6,082 SSR markers were developed.

Identification of Molecular Markers Linked To Traits

Molecular markers are used to locate genes and QTLs responsible for the inheritance of traits. An important step in the process of trait mapping is the development of mapping populations. Several mapping populations have been developed to determine chromosomal regions having genes or QTLs for traits of interest in yam [43-47]. Earlier efforts in trait mapping in yam predominantly focused on disease resistance. Mignouna *et al*. [48] applied a bulked segregant analysis on an F1 progeny emanating from a cross between TDr89/0144 (resistant male parent) and TDr87/00571 (susceptible female parent) with the aim of detecting RAPD markers linked to yam mosaic virus disease resistance. They identified a single locus conditioning yam mosaic virus resistance in TDr89/01444 and named it Ymv-1. They found two RAPD markers tightly linked in coupling phase with Ymv-1 on the same linkage group. The two markers were successfully utilized to identify Ymv-1 resistant genotypes among D. rotundata varieties and in resistant F1 genotypes from crosses, demonstrating their potential usefulness in marker-assisted selection. Mignouna *et al*. [45] applied 469 co-dominantly scored AFLP markers segregating in an intraspecific F1 cross to generate a genetic linkage map of D. alata. Quantitative trait loci mapping discovered one AFLP marker E-14/M52-307 positioned on linkage group 2 that was associated with anthracnose disease resistance, explaining 10% of the total phenotypic variance. A genetic linkage map of the D. rotundata was developed based on 341 co-dominantly scored AFLP markers segregating in an intraspecific F1 cross [44]. One QTL for yam mosaic virus resistance was associated with the marker P16/M16-126 on linkage group 1, which explained 24% of the total phenotypic variance and two QTLs linked with P14/ M22-418 and P17/M22-238 on linkage group 8 which explained 22 and 35% of the phenotypic variance on the maternal linkage group, respectively. Two QTLs for yam mosaic virus were also identified on the paternal linkage group 4 and were associated with the markers P12/M19-241 and P16/M15-81 that explained 13 and 16% of the phenotypic variation, respectively. In a gene expression study of D. rotundata using SuperSAGE transcriptome profiling to identify flowering and sex-related genes, Girma *et al*. [49] found 88 tags significantly differentially expressed in male, female and monoecious plants. Eighteen of these 88 differentially expressed SuperSAGE tags corresponded to previously implicated genes for flower development and sex determination in many plant species. Genetic mapping (GWAS and linkage mapping) studies are currently ongoing at IITA, Nigeria to identify QTLs for various traits in D. rotundata and D. alata under the ongoing AfricaYam and NSFBREAD projects. These studies will generate additional genomic information and resources to facilitate marker-assisted breeding in yam. Identification of the key genes underlying relevant traits will expedite their speedy incorporation into elite cultivars or farmer- preferred varieties via marker-assisted selection.

Genetic Engineering and Gene Editing For Yam

Genetic engineering has emerged as an important alternative and complementary methodology to improve crops including yam. The application of transgenic methods to yam improvement is particularly compelling due to the difficulties associated with conventional yam breeding. However, an efficient plant regeneration system is the main prerequisite for the achievement of successful transformation [50]. Due to its ease of accessibility, ability to transfer low copies of DNA fragments carrying the desirable genes at higher efficiencies with minimal cost as well as the transfer of very large DNA fragments with low rearrangement, Agrobacterium-mediated gene delivery system is the most preferred [51, 52]. Quain *et al*. [11] developed a transient transformation of D. rotundata using Agrobacterium but generated no transgenic plants. Nyaboga *et al*. [50] developed the first fast, efficient and reproducible protocol for Agrobacterium-mediated transformation of D. rotundata. This protocol resulted in the generation of stable transformations and the regeneration of complete transgenic plants. This advancement in Agrobacterium-mediated transformation has laid the foundation for the full implementation of genetic engineering and gene editing in yam. Targeted genome alteration approach has become a promising tool for crop breeding. The recently established gene-editing technique, the clustered regularly interspaced short palindromic repeats (CRISPR/Cas9) system, resulting from the adaptive immune system of Streptococcus pyogenes, has been demonstrated to be a potent tool for targeted genome editing in many species [53]. The Genome-Enabled Platforms for Yam Project was launched in 2016 in collaboration between scientists at IITA and Iowa State University (https://www.nsf.gov/award searc h/showA ward?AWD_ ID=1543888). Additionally, a genome-editing tool for yam using phytoene desaturase (a key enzyme in the β-carotene biosynthesis pathway, which converts the colourless phytoene to coloured carotenoids) as a marker is being developed [54]. Targeted traits for yam gene editing and genetic engineering include resistance to yam mosaic virus and anthracnose diseases, herbicide tolerance and nematode resistance. Feng *et al*. [53] successfully applied the CRISPR/Cas9- mediated targeted mutagenesis in D. zingiberensis using an A. tumefaciens- mediated transformation method aimed at the farnesyl pyrophosphate synthase gene (Dzfps) (an essential gene involved in the synthesis of secondary metabolites). The successful application of the CRISPR/Cas9 technology to inactivate the endogenous banana streak virus by editing the virus sequences to develop resistant plantain [55] clearly indicates that such an approach can be implemented to develop yam varieties resistant to yam mosaic virus, hitherto, as in the case of banana streak virus, viruses affecting yam have also been found to be integrated into the genome of yam [56, 57].

Genome editing should therefore be incorporated into the yam improvement programme and traits to be targeted should be decided in consultation with breeders. The ethics and regulation of genetically modified and gene-edited crops should be taken into serious consideration in the application of these technologies. The major challenge of the CRISPR/ Cas9 technology is that it may recognize sequences with up to five mismatched bases suggesting high rates of off-target effects [58].

PROPERTIES OF YAM CULTIVARS

Anti-diabetic potential of yam

Nimenibo–Uadia [59], reported the presence of saponins, flavonoids and cardiac glycosides from D. dumetorum during the phytochemical screening of the aqueous extract of the tuber. The author demonstrated significant hypoglycaemic activities which at ($p<0.05$) considerably reduced elevated blood levels of triacylglycerol, cholesterol and β–hydroxybutyrate associated with alloxan-induced diabetes mellitus.

Antioxidants Potential of Yam

The oxidative damage and human diseases caused by environmental chemicals involves the free radicals resulting in cellular damages, such as cancer and cardiovascular diseases. Natural antioxidants are very important, play major role in the oxidative prevention by safely interacting with the free radicals, and terminate the chain reaction before vital molecules are damaged. The phenolic compounds flavan-3-ol, such as catechin or epicatechin, procyanidin, dimers B-1 and B-3 have been reported in D. alata, D. cayenensis, D. cirrhosa,

D. dumetorum, D rotundata and D bulbifera [60, 61]. Likewise, presence of phenolic acid compound has been reported in Nigerian brown yam. The browning of the yam flour was as a result of the polyphenolic compounds in yam which undergo poly-phenolic oxidase-catalysed reactions to form o-quinones, their primary oxidation products, which then react with other components to form brown polymeric compounds [62]. Also, amino acids and proteins in the yam, when heated, can react non-enzymatically with sugars forming brown-colored compounds commonly called Maillard reaction products [63]. Browning reaction products such as pyrazines and acetylfurans have been reported to exhibit antioxidants activity to ameliorate peroxidative damage, induced by free radicals and xeno-biotics, to membranes and tissues. Additionally, Dioscorea sp of yam tuber from Nepal was reported to be a natural antioxidant source. The phenol content ranges from 13 -166 mg/100 g was observed, the organic acids; succinic acid, citric acid, malic acid and oxalic acids were 1316 mg/100 g, 274 mg/100 g, 147and 110 mg/100 g, fresh weigh respectively [64].

Anti-Cancers and Anti-Fungal Properties of Yam

During the ethanol extract of D. panthaica, two novel Furostanol compounds; Dioscoresides 1 and 2 were isolated which when tested in vitro on A375-S2, L929 and HeLa cell lines exhibited cytotoxic activity [65]. In addition, the fractionated saponin extract of D. villosa was reported to displayed antifungal activity using the broth dilution method against Candida albicans, Candida tropicalis and Candida glabrata [66]. The result corroborate with the author previous findings on the antifungal activity of spirostanetype saponins isolated from D. cayenensis [66].

Immune Booster and Anti-Ageing Capability of Yam

Diosgenin, one of the steroid sapogenins was reportedly isolated from Dioscorea species of Mexican origin. Diosgenin has been commercially used to produce steroid hormones such as cortisone, estrogen, and progesterone through in-vitro chemical modification [67]. This steroid significantly reduced serum lipid peroxidation, lowered serum triglycerides and increased HDL levels in the selected older people. Its extract has been a dietary precursor of Dehydroepiandrosterone (DHEA). This is because DHEA declines with age and low DHEA level correlated with high mortality rate, since ageing involves reduced protein synthesis, increased risk of chronic disease, and risk of cancer, increased level of DHEA is essential to reverses immunosenescence and restore cancer immunity [68]. Likewise, Diosgenin extract of D. villosa has been used as a steroid precursor of progesterone, to minimize post-menopausal symptoms and for treatment of low progesterone levels [69] and its anti-collagenase activity and the possibility of skin disorders prevention through Sapogenins incorporation in cosmetics has been investigated [66].

Anti-sickling potential of yam

The harmless heterozygous sickle cell trait (SCT) occurs more frequently in Africans than in African-Americans in the United States, the active form of sickle cell anemia (SCA) is quite rare. This rarity SCA in Africans was in the past attributed to an unknown environmental protective factor. The protective factor against SCA was identified to be thiocyanate (SCN-), [66] which are found in African yam (Dioscorea spp). Yam is the second richest known food source of thiocyanate with range of about 50- 60 mg/10 g. This value is higher when compared with other vegetables which ranges between 0.4 - 10.1 mg/10 g. Thiocyanate a precursor of cyanate physiologically present in mammalian fluids is obtained from the beta-cyanogenetic glucosides in food plants, and from nitrilosides also known as vitamin B17 [70]. Nitrilosides form thiocyanate upon their hydrolysis in the body in the presence of sulfur donor cysteine or methionine through the action of rhodanese; an enzyme found in all normal body tissues [71]. Its hematopoietic effect to ameliorate sickle cell anemia has been clinically observed. Nitriloside and thiocyanate were found to elevate plasma thiocyanate many fold in rats and in humans [72]. Cyanate, the end-product of thiocyanate, has irreversibly inhibited the sickling of red blood cells in vitro and extends the life span of treated sickle cells to near normal range in vivo, consequently, prevent the general manifestation of sickle cell anemia.

Phyto-chemicals of yam

The presence of phytochemicals constituents in yam such as phenol, alkaloids, flavonoids, saponins, and tannins in various yam species show the potential antioxidant and free radical scavenging properties. Flavonoids are known to check lipid peroxidation and there is a correlation between flavonoid and antioxidant activity [73], alkaloids are contain large group of nitrogenous compounds which used as cancer chemotherapeutic agents [74]. Tannins possess anti carcinogenic potential and also reduce risk of cancer due its antioxidant activity that presence which control the oxidative damage of cell. Phytochemicals composition of the various yam species, Phytochemicals, as compounds which occurs naturally in plants, form part of plants defense mechanisms against diseases [75]. They are classified into primary and secondary, based on their activity in plant metabolism. The primary ones comprise of sugars, amino acids. Yams, particularly D. domentorum and D. cayenensis have been well reported by herbalist community for generations due to their induced fertility in males [76]. This may be due to the presence of steroids hormones such as diosgenin, which have been identified from yams [77]. Diosgenin from yams have been used as precursors for the synthesis of hormones and corticosteroids which increase fertility in males [77]. The phytochemicals ingredients detected in the D. bulbifera. The average concentrations of the phytochemicals compounds in the bulbils were as follow; saponin (21.37 mg/g), terpenoid (20.40 mg/g), cardiac glycosides (12.37 mg/g), flavonoid (6.33 mg/g), tannin (4.25 mg/g) and phlobatannin (1.56 mg/g).

Phyto-chemicals interactions with edibility of yam

The edible, mature, cultivated yam does not contain any toxic phytochemicals. However, bitter phytochemicals tend to accumulate in immature tuber tissues of *Dioscorea rotundata* and *D. cayenensis.* These phytochemicals may be polyphenols or tannin-like compounds [78]. Wild forms of *D. dumetorum* do contain bitter phytochemicals, and hence are referred to as bitter yam. Bitter yams are not normally eaten except at times of food scarcity. Traditionally, they are usually detoxified by soaking in a vessel of salt water, in cold or hot fresh water or in a stream. The bitter phytochemical has been identified as the alkaloid dihydrodioscorine, while that of the Malayan species, *D. hispida*, is dioscorine [79]. These are water soluble alkaloids which, on ingestion, produce severe and distressing symptoms [80]. Severe cases of alkaloid intoxication may prove fatal as reported in the case of poisonous yam. There is no report of alkaloids in cultivated varieties of *D. dumetorum*.

*Dioscorea bulbifera*otherwise called the aerial or potato yam and is believed to have originated in an Indo-Malayan centre. In Asia detoxification methods, involving water extraction, fermentation and roasting of the grated tuber are used for bitter cultivars of this yam. The bitter phytochemical contents of *D. bulbifera* include a 3-furanoside norditerpene called diosbulbin. These substances are toxic, causing paralysis. Extracts are sometimes used in fishing to immobolize the fish and thus facilitate capture. Toxicity may also be due to saponins in the extract. Zulus use this yam as bait for monkeys and hunters in Malaysia use it to poison tigers. In Indonesia an extract of *D. bulbifera* is used in the preparation of arrow poison [80].

Nutritional value of yam

Yams are the one of the good source of vitamins, minerals, and fiber, and it contains about 158 calories, 37 grams of carbs, 2 grams of protein, 0 grams of fat, and 5 grams of fiber. Yams are rich in potassium and manganese, which are essential for good bone health, growth, metabolic function, and heart health [81]. It also contains about 5 g of fiber, 19 mg of calcium, Yams are nutrient-dense tuber vegetables that come in many colors. They're a great source of fiber, potassium, manganese, copper, and antioxidants. Yams is linked to various health benefits and boost brain health, reduce inflammation, and improve blood sugar control, [82]. Yam is considered as the most nutritious of the tropical root crops [83]. It contains approximately four times as much protein as cassava, and is one of the major root crop that exceeds rice in protein content in proportion to digestible energy [84]. The amino acid constituents of yam protein is suboptimal in sulfur-containing amino acids (cysteine and methionine), but the overall rating for essential amino acids is much high and superior to sweetpotato [85, 64]. Yam is one of the good sources of vitamins A and C, and of fibre and minerals. Its relatively low calcium content is related to low concentrations of calcium oxalate, an antinutritional factor [84]. It is also low in the antinutrients phytate [84] and trypsin inhibitor [86].

Yam processing methods and biological implications

Cooking and processing of yam

In much consideration, the greater quantity of the world's yam crop is consumed fresh. Many traditionally processed yam products are made in most yam-growing areas, usually as a way of utilizing tubers that are not fit for storage. In most cases, fresh yam is peeled, boiled, and pounded until sticky elastic dough is produced. This is called pounded yam or yam fulu.

The only processed yam product traditionally made at village level is yam flour. Yam flour is regarded as a low nutrient rich substitute for the freshly pounded yam because it is often made from damaged tubers. However, is usually a different situation in the case of the Yoruba ethnic group in Nigeria. Yam flour is favoured in the Yoruba area where the reconstituted food is known as amala. To a limited extent, yam flour is also manufactured in Ghana where it is known as kokonte. The nutritional value of yam flour is the similar as that of pounded yam.

Preparation of yam flour

The tubers are sliced to a thickness of about 10 mm, more or less, depending on the dryness of the weather. The slices are then parboiled and allowed to cool in the cooking water. The parboiled slices are peeled and dried in the sun to reduce the moisture content as well as the cyanide composition

[87].The dried slices are then ground to flour in a wooden mortar and repeatedly sieved to produce a uniform texture. Today small hand-operated or engine-driven corn mills or flour mills are increasingly used to enhance this process.

Industrial processing

On commercial basis, yams have not been processed to any significant extent. Dehydrated yam flours and yam flakes have been produced by sun drying. The manufacture of fried products from *D. alata* has also been attempted recently. Both chips and French fries have been manufactured. Preservation of yam in brine has been attempted, but with little success.

Two attempts have been made to commercialize the process involved in the production of pounded yam because of the fact that it has so much prestige and is the most popular way of eating yam. The first involves the production of dehydrated pounded yam by drum drying. This product could then be reconstituted without further processing. This method dated far back in the mid-1960s was first attempted in Côte d'Ivoire, under the trade name "Foutoupret", by air drying precooked, grated or mashed yam [80]. Onayemi and Potter [88] used drum drying to produce a flake which can easily be reconstituted into pounded yarn by mixing with boiling water. This is the basis of the commercial product called "Poundo" in Nigeria, which was initially successful. To reduce wastage of raw material, peeling is done by using a10 percent lye at 104°C with varying immersion times depending on the cultivar of yam [89]. Sulphite is added to prevent enzymic browning.

In the second commercial project a type of food processor resembling a blender was developed. The yam is cooked, fumed and churned in a process equivalent to pounding, to give enough pounded yam for two to four servings. Both projects appeared at first to be very successful, but later people reverted to the manual pounding of yam which gives a characteristic viscosity and firmness that is difficult to simulate mechanically. Attempts to manufacture fried yam chips, similar to french fried potatoes have been reported from Puerto Rico.

Effects of processing methods on the nutrient and antinutrient composition of yam

Most domestic cooking methods have effects on nutritional quality of foods by reducing the level of antinutrients and some nutrients, while enhancing other nutrients as well [90, 91, 12]. Intra and inter varietal diversity of foods is being promoted as a means of dietary diversity to tackle malnutrition in all its ramifications and, providing nutrition information about yam may promote its popularity and importance.

The mineral composition of raw and processed yam products varies significantly. As reported by Ifon and Bassir [92], raw yam has very low level of sodium, calcium, and phosphorus, magnesium, iron, and zinc however, has high level of potassium. The very low level of sodium in raw yam compared with potassium is a good advantage for the yam to be suitable for consumption by hypertension patients where sodium: potassium ratio is expected to be low. Generally, processing yam into different products resulted in significant reduction in value for most of the minerals, the reduction being more pronounced when boiling is used. However, roasting and frying significantly increased the potassium and phosphorus content of the products compared with the raw yam product. Also, preparing yam into porridge and Ojojo significantly improved the sodium, potassium, calcium, phosphorus, iron and zinc content of the products compared with raw yam. The increase in the mineral content of these products as reported by Adepoju *et al.* [93] was believed to be contributed in part by the added salt and ingredients, and in part by bioconversion of the yam components, leading to significant reduction in value of antinutrients such as phytates and oxalates which combine with these minerals.

Raw yam was reported to have very low level of b-carotene, thiamine and riboflavin. However, it has been reported to have moderate level of ascorbic acid content [93]. Processing methods such as frying, roasting, boiling, significantly increased the b-carotene content of yam. The increased level of the b-carotene content of processed yam is due to either reduction in moisture content of yam or addition of vegetable oil during the processing. The reduction in the vitamin contents has been reported to be due to heat destruction or loss through leaching of these vitamins into the cooking water [90, 84].

The level of antinutrients in raw yam is very lowand is unlikely to constitute any hindrance to digestibility of nutrients from other food sources in the human body. The different processing methods generally led to significant reduction in the levels of antinutrients inprocessed yam. This supports the findings that processing significantly reduce the level of antinutrients in processed foods [10].

Effects of Processing Methods on the Phytate Content of Yam

Phytate is a storage form of phosphorus which is found in plant seeds and in many roots and tubers [94]. Phytic acid has the potential to bind calcium, zinc, iron and other minerals, thereby reducing their availability in the body [95, 96]. In addition, complex formation of physic acid with proteins may inhibit the enzymatic digestion of the protein [97].

Recently, Marfo and Oke [87] reported that cassava, cocoyam and yam contain 624 mg, 855 mg and 637 mg of phytate per 100 g respectively. Fermentation reduced the phytate level by 88 percent, 98 percent and 68 percent respectively, reduction being rapid within 48 hours but very slow after 72 hours processing. Thus, processing into fermented foods reduce the phytate level of root crops sufficiently to nullify its adverse effect. The loss of phytate during fermentation is due to the enzyme phytase, naturally present in the tubers or secreted by fermentative microorganisms. Processing into nbo or kokonte resulted in a loss of about 18 percent of phytate in cassava and approximately 30 percent each in cocoyam and yam. Oven-drying has only a small reductive effect on the phytate content compared with fermentation. Cooking also has a significant effect, resulting in decrease of phytate of 62 percent, 65 percent and 68 percent respectively in yam, cocoyam and cassava.

The table 1 below provides the percentage loss in phytate resulting from each processing methods expressed as a percentage of total phytate content

Table-1: Effect of Processing on Phytate in Yam

	Fresh and Unprocessed	**Sliced and Cooked (Ampesi)**	**Flour cooked into a paste (Tug, kokonte)**	**Dried granular powder (gari)**	**Gari made into a paste**	**Fufu (cooked and pounded)**
Yam	637	239	412	188	179	209
% Lose	-	62.4	30.8	70.4	71.8	67.1

Source: Marfo and Oke, 1988

STORAGE TECHNIQUES OF YAM

Yam storage is very important to ensure food security, future consumption, replantation (yam seeds) in another season, higher market prices. Sometimes yam farmer's encounters a situation in which they had to either sell or consume all their yam products at lesser prices due to difficulties in storage and preservation of yam [98]. Therefore proper storage of yam plays a crucial role for farmers, as well as for future consumption. The traditional methods which are employed for yam storage are: 1) Pit storage 2) Clay barn storage 3) Improved yam barn 4) Vertical tying 5) Straw shelter.

1) **Pit storage:** In this technique, large pits are dug on the farm ground. The pits should be large enough to accommodate the entire harvest .The yam tubers are then placed into this pit with the tails end down. Next, the filled pits are covered with mounds made on them. The function of mound is to direct the rain water away from the stored yams. There should not be any ant hills or water logging areas nearby the dug pit, and it should be dug under shaddy areas. Yam tubers should not be covered with straw before covering with soil as this may lead to termite attacks on tubers. This method is commonly used for milk yams.
2) **Clay barn storage:** Barns are basically huts constructed of local materials like, clay, straw, sticks, vines, woven mats which are generally used for storage of ware yams. Depending upon the locality and storage conditions, different types of bans can be constructed. Clay barn is one of its types which is constructed in the form of a hut, and is found mainly in savannah regions, with clays walls covered with a roof of straw. Favourable temperature for yams can be achieved by usage of clay and straw as a construction material. If well catered, the life span of clay barn can be as long as 20 years.
3) **Improved yam barn:** It is a storage structure which is built on a stand of about 1m high. Generally it is built on sawn timber. Rodent guards are fixed to these stands to provide adequate protection against rodent attack. This barn should be constructed away from the trees to prevent the attack of the rodents that can jump into it. Shadrack and his colleagues [99] had constructed an improved yam barn using bamboo, Borassus palm, woven straw mat (zanna mat) and spear grass which had shelves in it. It's main peculiarity was that it was strong enough to withstand the load of 5000 yam tubers at full capacity without bucking in. It's other features include water proofing, protection against rodents, theft, low cost, good ventilation.
4) **Vertical tying:** In this technique, tubers are tied with ropes one above the other, on the vertical wooden stakes which is constructed about 3m high, spaced 50 cm apart ; stabalized by horizontal poles. It is tedious process as each tuber is tied separately and is relatively expensive [80, 100, 101]

The above described storage techniques have their own advantages and disadvantages which are illustrated in table 2. It should be taken into consideration by farmers while selecting a particular storage technique.

Table-2: Advantages and disadvantages of various storage techniques

Sr No	**Storage Technique**	**Advantages**	**Disadvantages**
1.	Pit storage	a). Weight loss of tuber is very less b). Prevents attack of rodents and animals c). better protection against higher temperatures d). less labour work required	a). high chances of nematodes infection b). Due to inadequate aeration and direct contact of tubers, it may result into tuber rotting.
2	Clay barn storage	a). protection from rain, sun and solar radiations b). easy inspection of tubers c). usage of affordable, natural and cheap local materials for construction	a). construction process is tedious and time consuming b). insufficient aeration c). difficult to inspect d). intensive labour required during storage e) inadequate protection from pests and rodents
3	Improved yam barn	a). easy inspection of tubers b). adequate protection against sun, rain, rodents c). good aeration d). incorporating shelves helps increase the quantity of storage.	a). expensive construction b).intensive labour required for stacking and sometimes may even cause bruises
4	Vertical tying	a).Perfect aeration b). Control and removal operations are easy c) most commonly used technique	a). Yams are easily attacked by insects and rodents b). tedious and time consuming process as each tuber is tied separately c). easily prone to damage and rotting during rainy season.

CONCLUSION

Yam tubers have always remained one of the essential dietary components for humans over the years. It is one of nature's gift to humans and is regarded as an energy contributor. However, is also packed with several other nutritional and antimicrobial, anti-diabetic, anti-fungal, anti-ageing, anti-cancer and many properties. This review has additionally summarized various aspects of yam such as its storage, processing, nutritional values, hybridization and genetic improvement. Further detailed studies on the bioactive compounds of yam will help in the research on the industrial and medical potentials of the various cultivars of yam.

Author's contribution and conflicts of interests

All authors researched, co-wrote, read and approved the different aspects of the review. Authors declare that they are no conflict of interests as regards this article.

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