Chapter

Congolese Traditional Foods as Sources of Antioxidant Nutrients for Disease Prevention

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Abstract

Oxidative stress, characterized by excessive production of reactive species, is involved in several chronic diseases such as cardiovascular, chronic obstructive pulmonary, sickle cell, chronic kidney, neurodegenerative, and cancer. The negative impact of ROS and RNS, produced by endogenous and exogenous processes, is neutralized by antioxidant defenses. Given the importance of oxidative stress to human health, the use of antioxidants as therapy directs medical research toward the specificity of antioxidants causing each disease. Fruits and vegetables contain antioxidants, such as nutraceuticals, pharmaceuticals, and phytoceuticals, the consumption of which reduces the risk of developing chronic diseases. Flora of African countries is endowed with plant species that would make a putative source for new antioxidants. This article reports antioxidant activities of traditional foods from Democratic Republic of the Congo. Further studies are needed to ensure mechanisms of their functionality in the human body.

Keywords: antioxidants, Congolese diet, insects, oxidative stress, phytochemicals, reactive oxygen species, selenium, vegetables

1. Introduction

Oxygen metabolism, physiologically and regularly, produces small amounts of reactive oxygen species (ROS) to serve as an essential signaling mechanism for the maintenance of homeostasis and redox reactions in the cell [1]. Highly reactive ROS, associated with inflammation, cause tissue damage against which the cells of the human body protect themselves by various free radical defense mechanisms. However, when ROS levels are high due to an imbalance between their production and antioxidant defense mechanisms, oxidative stress occurs [2]; a situation where the cell no longer controls the excessive presence of radical's toxic oxygen, responsible for genomic and metabolic modifications, which favor the development of several diseases, in particular diabetes, cardiovascular diseases, cancer, respiratory and rheumatic diseases, and endometriosis [3]. Endogenous antioxidants and the wide variety of antioxidants in the diet, once present in all compartments of the organism, are involved in the protection of membranes and intra and extracellular environments against free radicals, and therefore against the diseases for which they are responsible. The objective of this review was to provide the therapeutic potential of Congolese traditional foods with antioxidant capacities useful in the management of various pathologies associated with oxidative damage.

2. Oxygen and ROS

Oxygen, essential for life, can also become a source of toxicity and cell degeneration. Indeed, at the level of the electron transport chain, oxygen undergoes a tetravalent reduction, which transforms it into water-generating ATP. During this process, 2% of the oxygen escapes and undergoes a monovalent reduction of one electron at ubiquinone producing the superoxide radical ($\bullet O_2^-$) with an unpaired electron on the outer shell, which is seeking to return immediately to a stable state by donating an electron or taking one from another molecule, finds itself in an energy instability that gives it its particular reactivity with respect to other atoms or molecules [4]. O_2^- can also be produced from NADH-dehydrogenase located in the inner mitochondrial membrane or from NADPH oxidase present in vascular endothelial cells [5]; it can also result from the auto-oxidation of neurotransmitters such as adrenaline, noradrenaline, dopamine, cysteine thiols, and reduced coenzymes, such as FADH2, as well as the detoxification of toxic pollutants and drugs, by the system of cytochromes P450 present in the endoplasmic reticulum [6]. The neutrophil respiratory burst and xanthine oxidase, NO synthase, and eicosanoids are also cellular sources of superoxide anion production [7]. Having a certain toxicity and being at a low concentration, the superoxide radical is eliminated by superoxyde dismutase (SOD), generating hydrogen peroxide (H_2O_2), which can also be produced by a bielectronic reduction of oxygen in the presence of oxidases of peroxisomes or by oxidative deamination of certain amines of the outer mitochondrial membrane. In the presence of metal cations, such as Fe^{2+} [8] or Cu [9], hydrogen peroxide generates, through the Fenton reaction, the hydroxyl radical ($^{\bullet}OH$), which is particularly harmful to biological tissues.

Other oxygen free radicals such as the perhydroxyl radical (HO_2), the peroxyl radical (RO), and the alkoxyl radical (RO_2) can also be formed during cellular metabolism. Another radical species is nitric oxide, which is produced by the various NO synthases (or NOS) of endothelial cells or macrophages for neuron-mediated purposes [7]. Inflammation is also an important source of oxygenated radicals produced directly by activated phagocytic cells, which are the site of a phenomenon called oxidative explosion consisting of the activation of the NADPH oxidase complex, an enzyme capable of using molecular oxygen to produce large amounts of superoxide anions at the cell membrane. This mechanism, when controlled, is essential in the fight against infection because it allows the phagocytosis of bacteria and foreign bodies. Radiation can generate free radicals, either by splitting the water molecule in the case of ionizing X or γ rays or by activating photosensitizing molecules in the case of ultraviolet rays [10, 11].

In general, ROSs include free radicals of oxygen itself as well as singlet oxygen ($^1O_2$) and non-radical reactive oxygen species, such as hydrogen peroxide (H_2O_2), RO_2H, peroxynitrite ($ONOO^-$), and HOCl, whose toxicity is significant [12].

Due to their reactivity, ROSs participate in phagocytosis, cell signaling, activating fertilization, improving muscle glucose uptake, and replenishing muscle glycogen stores [13–15] and have a bactericidal effect [16]. In addition, ROSs regulate most of the physiological functions of the body, in particular transcription factors, which activate protective genes for the cell contributing to the processes of cell repair and regeneration as well as the phenomenon of apoptosis [17].

To have a level of ROS beneficial for cellular life, it is necessary to maintain a balance inside the cell between the systems that generate free radicals and the nonenzymatic antioxidant systems [18, 19].

3. Oxidative stress

Present in excess in the body, ROS create an imbalance between prooxidant sources and antioxidant systems, generating "oxidative stress." This oxidative stress, resulting from the excessive presence of toxic oxygen radicals, causes oxidative damage to lipids, DNA, or proteins, which is the basis of many cellular dysfunctions, and the activation of the expression of genes coding for pro-inflammatory cytokines or adhesion proteins, phenomena that are partly responsible for a large number of diseases such as cancer, cardiovascular disorders, and neurodegenerative diseases [20, 21].

This disruption of the antioxidant/prooxidant balance in favor of the prooxidants can come from heavy metal poisoning; irradiation, a nutritional deficiency in one or more of the antioxidants such as vitamins or trace elements, abnormalities genetics responsible for poor coding of a protein either enzymatically antioxidant, synthesizing an antioxidant, regenerating an antioxidant, coupling defense to energy, or of a promoter of these same genes that the mutation will render unable of reacting to an excess of radicals or ischemia/repercussions following thrombosis [22–24]. In general, oxidative stress is the result of several of these factors and occurs singularly in a specific tissue and cell type, and not throughout the body.

4. Physiological and pathological oxidative stress

Oxidative stress, resulting from high levels of toxic ROS and RNS, while having a physiological role, constitutes a favorable ground for the development of various pathologies. Generated in small quantities under normal conditions, ROSs play a role of capable secondary messengers, especially in regulating the phenomenon of apoptosis or of activating transcription factors as well as in maintaining cellular homeostasis [25]. During the process of fertilization, the sperm cells secrete large amounts of ROS to pierce the membrane wall of the egg [26]. Free radical nitric oxide or $NO^{\bullet}$, synthesized by endothelial cells, has regulatory effects for the maintenance of vascular tone, neurotransmission, renal function, and other physiological functions.

However, in the event of oxidative stress, the strong reactivity of ROS with respect to biological substrates can induce deleterious oxidative damage, which promotes the appearance of several diseases and the complications associated with them. The oxidation of lipids, for example, is a factor favoring the occurrence of cardiovascular diseases, while that of DNA is found in various stages that lead to the development of cancers [27].

The development of molecular biology has also clarified the important physiological role of ROSs, which, at high levels in the body, activate the expression of genes coding for pro-inflammatory cytokines or proteins adhesion, thus, becoming pathological. By reacting with DNA and the memory of all the biochemical composition of living beings, ROSs induce five main classes of oxidative damage, namely, oxidized bases, abasic sites, intra-strand adducts, strand breaks, and DNA-protein bridges. If these structural alterations are not "repaired," they will disrupt the DNA replication mechanisms and lead either to reading and synthesis errors by unfaithful translesional DNA polymerases resulting in a point mutation in the genome, or an impossibility of DNA copying, which will result in the initiation of the programmed suicide of the cells by a mechanism called apoptosis [28]. Not only smoking, alcoholism, obesity, and intense physical exercise but also our bad eating habits abnormally increase the production of AOEs in our bodies [29]. A diet low in fruits and vegetables and rich in antioxidants (vitamins C and E, carotenoids, polyphenols) promotes a drop in antioxidant capacity. For the sake of prevention, having effective tools to properly assess the status of oxidative stress, in an individual, in order to make the necessary corrections to their antioxidant defenses and reduce the oxidative damage induced by ROSs at the DNA level, proteins, and lipids is an imperative necessity.

5. Oxidative stress and associated diseases

Oxidative stress is implicated in the occurrence of several acute and chronic pathologies [30]. Under physiological conditions, glucose, in the presence of metallic traces, can oxidize, releasing ketoaldehydes, H_2O_2, and $^{\bullet}OH$, which will lead to the cleavage of proteins or their glycation by attachment of the ketoaldehyde, forming an AGE derivative. This phenomenon of glycosylation, very important in diabetics, contributes to the fragility of their vascular walls and their elasticity [31]. Reactive oxygen species also attack mucopolysaccharides and, in particular, cartilage proteoglycans. By altering Krebs cycle enzymes, oxidative stress negatively influences oxidative phosphorylation, promoting acidosis and early fatigue. ROSs readily react with aromatic and sulfur amino acids, altering the functions of proteins that they constitute as well as their ability to properly bind to a receptor or specifically bind a ligand, which alters cell signaling [32]. The attack on membrane lipid double bonds induces peroxidation reactions that alter membrane exchange, barrier, and information functions, modify membrane fluidity and the functioning of numerous receptors and transporters and signal transduction; that of circulating lipids lead to the formation of oxidized LDL, which, captured by specific macrophage receptors, promotes the secretion of pro-inflammatory cytokines [33] and forms the lipid deposit of the atherosclerotic plaque of cardiovascular disease. Damage to lysosome membranes promotes the release of proteases into the cytosol [34], which will aggravate protein destruction and induce muscle catabolism, responsible for the onset of atrophy or even cachexia. The human brain is very sensitive to oxidative damage due to its richness in polyunsaturated fatty acids, its high oxygen consumption, and the presence of metals with active redox potential such as copper and iron [35]. As oxidative stress increases with age, it is considered a primary etiological factor in age-related degenerative pathologies such as Alzheimer's and Parkinson's diseases. Oxidative stress also plays a crucial role in the occurrence of other neurodegenerative pathologies of toxic-nutritional origin such as konzo, tropical ataxic neuropathy, and neurolathyrism [36]. In general, oxidative damage compromises cell viability or induces other cellular responses *via* secondary reactive species leading to apoptosis or cell necrosis. The most concerning pathologies are cardiovascular diseases, cancers, diabetes, neurodegenerative diseases, and endometriosis. The biological consequences of oxidative stress vary according to the dose and the cell type. If light stresses increase cell proliferation and the expression of adhesion proteins, medium stresses facilitate

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apoptosis, and strong stresses cause necrosis, while violent stresses disorganize the cell membrane, leading to immediate lysis. The amplitude of oxidative stress promotes the induction of cell death processes: apoptosis and/or necrosis [37].

6. Antioxidants

Antioxidants are molecules capable of neutralizing oxidative species and preventing their oxidative damage. In a healthy individual, reactive species and antioxidant defenses are in balance, although there may be a slow accumulation of oxidative damage with age [38]. This imbalance also occurs when there is a significant decrease in antioxidant levels without necessarily an increase in ROS production. Studies on the involvement of GSH during the aging of human embryo fibroblasts in culture have reported that the activity of the antioxidant enzyme glutathione peroxidase, as well as that of glutathione reductase, constantly decreases during aging cells until reaching a drastic low level in old cells [39]. To counteract the harmful effects of ROS following excessive ROS production, living cells and tissues are equipped with enzymatic systems, endogenous molecules, and antioxidants whose essential role is to destroy these intermediates before their deleterious action and to restore the redox balance [39]. According to their mode of action, we distinguish stoichiometric antioxidants and catalytic antioxidants. The stœchiométric antioxidants are vitamins, reduced glutathione (GSH), uric acid, N-acetylcysteine, nonsteroidal anti-inflammatory drugs, certain antibiotics, polyphenols, etc. capable of neutralizing one or even a few ROSs, mainly free radicals. The catalytic antioxidants have two subgroups [40]. The first are antioxidant enzymes with direct catalytic activity, such as superoxide dismutase (SOD) and glutathione peroxidase (GPx), and the second, with indirect catalytic activity, is represented by cofactors of antioxidant enzymes such as NADPH, GSH, and selenium or reducing enzymes involved in the repair of oxidation processes such as GSH reductase, thioredoxin reductase, and also ferritin, transferrin, and desferrioxamine. By neutralizing an oxidizing enzyme molecule or activating an antioxidant enzyme, hundreds or even thousands of ROS will be eliminated by the action of a single antioxidant molecule, hence their qualification as catalytic antioxidants. According to their nature, antioxidants are enzymatic and nonenzymatic. The enzymatic group includes the primary defense enzymes that directly neutralize free radicals or prevent their formation [38], such as superoxide dismutase, catalase, and glutathione peroxidase, while the secondary are glutathione reductase and glucose-6-phospho-dehydrogenase [41]. Nonenzymatic antioxidants are mainly exogenous molecules of food origins such as polyphenols, vitamins, carotenoids, sulfur molecules, and mineral elements.

7. Micronutrients, polyphenols, and phytochemicals as natural plant antioxidants

Phytochemicals are secondary metabolites, suchas polyphenols, terpenes, nitrogen/sulfur-containing compounds, and alkaloids, found in algae, fungi, plants, and some insects such as caterpillars, not directly involved in basic life processes but constitute compounds with multiple nutritional and therapeutic beneficial effects for humans [42]. During the overflow of the body's defense system following multiple attacks due to a poor lifestyle, there is a loss of activity of antioxidant enzymes, leading to sometimes irreversible cellular disorganizations going so far as to cause cell death. Under these conditions, the presence of natural antioxidants such as micronutrients, carotenoids, and polyphenols is essential to limit oxidative damage. The best carotenoid known is β-carotene, which is the precursor of vitamin A. Recent studies showed beneficial effects of glucosinolates, including regulatory functions in inflammation, stress response, phase I metabolism, and antioxidant activities [43]. The polyphenols, according to their antioxidant, antimicrobial, and anti-inflammatory properties, have demonstrated remarkable effects in many chronic diseases such as neurodegenerative diseases, diabetes, and cardiovascular diseases. It has been reported that phenolic and flavonoid compounds act as antioxidants to exert antiallergic, anti-inflammatory, antidiabetic, antimicrobial, antipathogenic, antiviral, antithrombotic, immunomodulatory, and vasodilatory effects, and prevent diseases such as cancer, heart problems, cataracts, eye disorders, and Alzheimer's [44].

Currently, a wide variety of polyphenols showed immunomodulatory activity by altering the formation of nitric oxide and eicosanoid proteins and by inhibiting pro-inflammatory cytokines and gene expression [45]. The polyphenols are found in plants, from the roots to the fruits. In this group, we have phenolic acids (caffeic, chrolorogenic acids…), anthocyanins, anthraquinones, catechins, coumarins, flavonoids (quercetin, kaempferol, rutin…), and tannins.

About micronutrients, essential components of the diet, studies on their supplementation that might improve health status have gained immense popularity. Fruits and vegetables, such as grapes, oranges, pomegranates, apples, plums, fresh garlic, carrots, and spinach from nature, have micronutrients and are rich in molecules with high antioxidant power, including tocopherols and polyphenols, which have ammunition to fight against free radicals and stop their chain oxidation reaction [46].

8. Traditional foods as potential sources of antioxidants, nutraceuticals, pharmaceuticals, and phytoceuticals

Traditional foods, eaten and prepared by groups of people who share a common religion, language, culture, or heritage, are an expression of the culture, history, and lifestyle of a people [47, 48]. The Democratic Republic of Congo (DRC) with the largest biodiversity in Africa and a variety of ecosystems: including nearly half the African rainforests, forest-savannah ecotones, savannahs, afro -mountainous forests, large and small lakes, rivers, and swampy forests [49], and lived by most than 450 ethnic groups, has more types of cuisines, rich in traditional dietary diversity from vegetables, fruits, herbal teas, legumes, nuts, seeds, mushrooms, and insects. In three of the twenty-six provinces of the DRC, Mbemba et al. have listed 163 different vegetables, 85 species of mushrooms, 35 kinds of roots and tubers as well as 64 species of fruits, nuts, and seeds, several of which are rich in proteins of good biological value: in lipids with unsaturated fatty acids, in vitamins, and in minerals [41]. The results of our studies on the phytochemicals, micronutrient contents, and antioxidant activities of traditional foods are reported in the table below.

Vegetables represent an important part of the diet of Congolese's population. Apart from conventional vegetables originating from other countries, there are traditional vegetables specific to each ethnic group. These vegetables are rich in nutrients such as proteins, lipids, vitamins, and minerals. Studies on several vegetables have shown their richness in various secondary metabolites (**Table 1**) with therapeutic properties that would justify their use in the management of certain diseases.

Scientific names	Vernacular names	Antioxidant nutrients	Total Polyphenol (mgGAE/g DW)	Total flavonoids (mgQE/g)	Antioxidant activity IC50 (µg/mL) *		References
					ABTS	DPPH	
Abelmoshus esculentus	*Dongo dongo*	Catechines, isoquercitrin, rutin, kaempferol, myricétine, quercétin	32.94 ± 0.93	-	86.27 ± 9.2	nd	[50, 51]
Abelmoshus moshatus	*Dongo*	Myricetin	36.32 ± 1.05	-	52.36 ± 2.1	71.45 ± 14.44	[50]
Entada gigas	*Futi, Nzembo futi*	Polyphenols	54.74 ± 0,49	37.08 ± 1,02	35.4 ± 0,96	45.5 ± 0,97	[52]
Hibiscus acetosella	*Ngai*	caffeoyl-hydroxycitric acid chlorogenic acid, quercetin-3-ga- lactoside	89.05 ± 11.92	-	44.98 ± 0.87	73.79 ± 17.20	[50, 51]
Hibiscus cannabinus	*Ngai ya nseke bakai*	quercetin-3-glucoside, kaempferol-rhamnoside, neochlorogenic acid	82.97 ± 3.27	-	64.72 ± 6.17	86.04 ± 4.32	[50]
Ipomoea batatas	*Kimbondji*	Cyanidin, chlorogénic acid, ferulic acid, quercetin	76.78 ± 3.20	-	47.76 ± 3.25	233.35 ± 63.53	[50, 51]
Manihot esculenta	*Saka*	Rutin, kaempferol-3-O-rutinoside, amentoflavone	86.4 ± 2.99	-	15.10 ± 1.13	20.15 ± 1.07	[50, 51]
Manihot glaziovii	*Sakasaka*	Rutin, kaempferol-3-O-rutinoside, amentoflavone, ferulic acid	107.71 ± 7.80	-	12.42 ± 2.08	20.5 ± 1.06	[50, 51]
Megaphrynium macrostachum	*Mikungu*	Flavonoids, Phenolic acids	32.69 ± 3.65	-	79.25 ± 10.29	503.5 ± 10.29	[50, 51]
Phytolacca dodecandra	*Tidi*	Glutamic acid, Cysteine, polyphenols, terpenoids, alkaloids	4.1 ± 0.65	0.32 ± 0.05	38.37 ± 7.98	62.23 ± 12.59	[53]
Psophocarpus scandens	*Kikalakasa*	Flavonoids, phenolic acids, manganese, magnesium	64.2 ± 0,58	40.78 ± 1,11	53.2 ± 0,97	62.81 ± 0,97	[52, 54]

Scientific names	Vernacular names	Antioxidant nutrients	Total Polyphenol (mgGAE/g DW)	Total flavonoids (mgQE/g)	Antioxidant activity IC50 (µg/mL) *		References
					ABTS	DPPH	
Rungia congoensis	*Kuinini*	Polyphenols, Terpenoids	69.16 ± 5.56		18.19 ± 1.8	42.76 ± 15.72	[55]
Salacia pynaerti	*Mbondi*	Polyphenols, anthocyanes, zinc, manganese, selenium	508.34 ± 14,42	31.62 ± 2.17	2.11 ± 0.48	9.48 ± 0.61	[52]
Sesamum angustifolium auct.	*Mundjingu*	Verbascoside, Flavonoids	63.76 ± 3.76	-	31.19 ± 1.07	48.3 ± 1.02	[50, 51]
Solanum aethiopicum	*Muteta*	Chlorogénic acid, tanins	32.24 ± 4.13	-	123.89 ± 16.15	282.49 ± 27.81	[50]
Solanum gilo	*Njiyo*	Flavonoids, tanins,	72.04 ± 1.70	-	29.51 ± 0.94	163.68 ± 30.41	[50, 51]
Tetrorchirdium congolense	*Nkelekete*	Flavonoids, tanins, Terpenes	241.54 ± 2,18	21.36 ± 0,65	3.65 ± 1.03	7.13 ± 2.14	[52]

(*) Antioxidant activities were evaluated using gallic acid and quercetin as controls. (IC50 Gallic acid: 0.71 ± 0.08 and 1.07 ± 0.10; Quercetin: 1.42 ± 0.04 and 3.21 ± 0.99 in ABTS and DPPH tests, respectively).
(-) not determined

Table 1.
Antioxidant activities of Congolese traditional vegetables.

From the results obtained, it appears that traditional vegetables contain polyphenolic compounds and flavonoids, which would give them antioxidant activities that are likely to fight against free radicals to attenuate oxidative damage to cells in the human body and spare it from chronic diseases. In order of importance, we align *Salacia pynaerti, Tetrorchirdium congolense, Manihot glaziovii, Manihot esculenta, Rungia congoensis, Sesamum angustifolium, Phytolacca dodecandra, Entada gigas, Hibiscus acetosella, Ipomoea batatas, Psophocarpus scandens* etc. In addition, the leaves of *Salacia pynaerti* contain calcium, zinc, manganese as well as glutamic, methionine, and cysteine, which participate in the synthesis of glutathione [54].

Spices are an integral part of the Congolese diet. Several traditional spices have been identified in the culinary habits of the Congolese people, often unrecognized and unexploited. Spice plants and vegetables, as well as their essential oils, are important sources of antioxidants phytochemicals and micronutrients including phenolics, terpenoids, and alkaloids. Consumption of these spices in diets would reduce the occurrence of nutritional deficiencies and health problems (**Table 2**).

Spice data indicate high polyphenol content in *Curcuma longa* rhizomes and high antioxidant activity from *Piper nigrum*. Studies have reported that the consumption of turmeric longa, mixed with black pepper, slows down or even decreases the proliferation of cancer cells [57]

Mushrooms are the second most common traditional food available to the Congolese rural population after vegetables. Although they are available periodically,

Scientific names	Vernacular names	Antioxidant nutrients	Total Polyphenol (mgGAE/g DW)	Total flavonoids (mgQE/g)	Antioxidant activity IC50 (µg/mL) *		References
					ABTS	DPPH	
Aeollanthus suaveolens Mart. ex Spreng.	*Dinkombo, Ngondi longo*	Phenolic acid, Flavonoids, Terpenes	26.30 ± 3.72	-	41.82 ± 3.99	61.12 ± 7.39	[50]
Curcuma longa	*Kingingingoni, mandjano, manga*	Terpenes, Polyphenols	204.96 ± 0.019	101.3 ± 0.004	72.95 ± 16.06	338.84 ± 80.61	[56]
Monodora myristica	*Mpeya*	Terpenes, Polyphenols	7.90 ± 0,22	0.92 ± 0.04	58.34 ± 1.63	102.33 ± 0,7	[55]
Ocimum basilicum L.	*Mazulu*	Phenolic acid, Terpenes	6.52 ± 0.18	-	38.37 ± 3.13	136.77 ± 15.64	[50]
Piper nigrum	*Ketchu*	Terpenes, Polyphenols	-	-	1.4 ± 0.13	11.64 ± 4.03	[56]
Raphia sese De Wild	*Bankulu*	Chlorogenic acid	10.08 ± 0.51	-	40.71 ± 1.05	518.8 ± 95.16	[50]

(*) Antioxidant activities were evaluated using gallic acid and quercetin as controls. (IC50 Gallic acid: 0.71 ± 0.08 and 1.07 ± 0.10; Quercetin: 1.42 ± 0.04 and 3.21 ± 0.99 in ABTS and DPPH tests, respectively).
(-) not determined

Table 2.
Antioxidant activities of Congolese traditional spices.

some species are sold dried throughout the year, such as *Auricularia delicata, Lactifluus edulis,* and *Schizophyllum commune* (**Table 3**). Mushrooms are a significant source of lipophilic compounds, phenolic and indole derivatives as well as carotenoids, and some vitamins having considerable antioxidant properties.

Despite low levels of polyphenols, mushrooms contain terpenoids as well as trace of elements such as zinc and selenium, and have appreciable antioxidant activity. *Auricularia delicata, Cantharellus symoensii*, *Lactarius ssp, Lactarius tenellus,* and *Marasmius collybia* have the best antioxidant activities.

Yams are an alternative for cereals and tubers with a moderate glycemic index, close to that of corn but lower than that of rice and cassava. Congolese yams are mainly represented by *Dioscorea* species. Numerous studies have reported the high nutritional value of *Diosocorea,* particularly as an alternative source of starch and some important micronutrients. Bioactivities and health benefits of yams such as Dioscorea extracts and other preparations have been related to the presence of phytochemicals, which possess antioxidant properties. Antioxidant activities are related mainly to radical scavenging capacity and positive effects on the cell's endogenous antioxidant system. Bukatuka et al. (2016) studied five Congolese edible Dioscorea and showed that the phytochemical screening revealed the presence of polyphenols, alkaloids, and terpenoids and they have shown a good antioxidant and anti-hyperglycemic activities (55), (**Table 4**).

Dioscorea alata, Dioscorea praehensilis, and *Dioscorea bulbifera* are endowed with useful antioxidant activities. Studies have reported that *D. bulbifera* and *D. praehensilis* have a hypoglycemic and antihyperglycemic effects [59].

Scientific names	Vernacular names	Antioxidant nutrients	Total Polyphenol (mgGAE/g DW)	Antioxidant activity IC50 (µg/mL) *		References
				ABTS	DPPH	
Amanita loosie Beeli	*Walenda*	Phenolic acid, terpenes	8.82 ± 0.01	45.65 ± 1.00	1862.1 ± 425	[50]
Auricularia delicata (Mont.) Henn. 1893	*Tshilebu*	Phenolic acid, terpenes	9.53 ± 0.12	39.31 ± 1.04	252.4 ± 15.5	[50, 58]
Cantharellus rufopunctatus var ochraceus Heinem.	*Upombo*	Phenolic acid, terpenes	4.73 ± 0.02	220.3 ± 17.40	1717.09 ± 522	[50]
Cantharellus sp	*Nahoto*	Selenium, Phenolic acids, Glutamic acid, cysteine, Lycopene	6.4 ± 0.02	144.9 ± 21.80	1367.73 ± 364	[50]
Cantharellus symoensii Heinem.	*Katshondjo*	Phenolic acid, terpenes	10.32 ± 1.09	41.1 ± 1.02	1815.52 ± 418	[50]
Lactarius ssp.	Bupeshele	Phenolic acid, terpenes	7.84 ± 0.03	46.77 ± 3.58	132.13 ± 16.47	[54]
Lactarius tenellus Verbeken & Walleyn, Persoonia	*Kafuka*	Phenolic acid, terpenes	5.96 ± 1.47	43.51 ± 1.04	1603.25 ± 294	[50]
Lactifluus edulis Verbeken & Buyck	*Wundje*	Phenolic acid, terpenes	5.12 ± 0.11	262.4 ± 20.74	1318.3 ± 259	[50]
Lentinus cf cladopus	*Bupup*	Polyphenols, Terpenoids, Zinc	22.79 ± 0.21	112.95 ± 0.98	291.07 ± 0.98	[58]
Marasmius buzungolo	Bututulu	Phenolic acid, terpenes	10.32 ± 0.08	82.79 ± 3.11	145.55 ± 27.3	[54]
Marasmius collybia	Nsudi ya Babakala	Phenolic acid, terpenes	9.43 ± 0.19	62.37 ± 2.49	109.65 ± 7.3	[54]
Pleurotus tuber-regium	*Butondi*	Polyphenols, Zinc	23.37 ± 8.16	153.82 ± 1,01	281.19 ± 0.95	[58]
Schizophyllum commune Fr.	*Tshikolokoto*	Flavonoids, Phenolic acids, lycopene, Vitamin C	9.77 ± 0.40	169.8 ± 23.80	307.61 ± 25.05	[50, 58]

(*) Antioxidant activities were evaluated using gallic acid and quercetin as controls. (IC50 Gallic acid: 0.71 ± 0.08 and 1.07 ± 0.10; Quercetin: 1.42 ± 0.04 and 3.21 ± 0.99 in ABTS and DPPH tests, respectively).

Table 3.
Antioxidant activities of Congolese traditional mushrooms.

The spontaneous flora of the DRC is very rich in food fruits called wild fruits and seeds, which unfortunately are little valued by the population. These fruits are rich in polysaccharides, micronutrients (vitamins, minerals), and secondary metabolites, such as polyphenols, whose therapeutic benefits are well known (**Table 5**).

Scientific names	Vernacular names	Antioxidant nutrients	Total Polyphenol (mgGAE/g DW)	Total flavonoids (mgQE/g)	Antioxidant activity IC50 (μg/mL) *		References
					ABTS	DPPH	
Dioscorea bulbifera	*Mukadi*	Polyphenols, Vitamin C	51.12 ± 0.5	3.33 ± 0.23	93.11 ± 11.21	109.65 ± 8.81	[59]
Dioscorea domentorum	*Bisadi*	Polyphenols	30.07 ± 0.3	-	1164.13 ± 28.32	916.22 ± 65.74	[59]
Dioscorea alata	*Mboma*	Polyphenols	9.85 ± 0.09	-	35.32 ± 1.34	283.14 ± 0.04	[59]
Dioscorea bulkiliana	*Bisadi*	Polyphenols	16.58 ± 0.16	2.6 ± 0.02	97.5 ± 9.4	510.51 ± 45.97	[59]
Dioscorea praehensilis	*Bisadi*	Polyphenols	13.35 ± 0.13	2.58 ± 0.3	83.34 ± 8.74	115.88 ± 10.93	[59]

(*) Antioxidant activities were evaluated using gallic acid and quercetin as controls. (IC50 Gallic acid: 0.71 ± 0.08 and 1.07 ± 0.10; Quercetin: 1.42 ± 0.04 and 3.21 ± 0.99 in ABTS and DPPH tests, respectively).
(-) not determined

Table 4.
Antioxidant activities of Congolese edible yams.

Scientific names	Vernacular names	Antioxidant nutrients	Total Polyphenol (mgGAE/g DW)	Total flavonoids (mgQE/g)	Antioxidant activity IC50 (μg/mL) *		References
					ABTS	DPPH	
Afromomum melegueta	Tundu ya nseke	Polyphenols, terpenes	158.28 ± 0.017	2.27 ± 0,03	17.38 ± 2.34	32.71 ± 6.73	[54]
Bombacopsis glabra	Nguba mputu	Polyphenols, flavonoids, terpenes	28.45 ± 1.34	0.52 ± 0.04	77.98 ± 2.56	85.31 ± 4.64	[54]

Table 5.
Antioxidant activities of fruits and seeds.

Afromum melegueta contains a high content of polyphenols and the best antioxidant activity. Their content in gingerol, shogaol, paradole, and oleanolic acid would be responsible for their hypocholesterolemic, antitumor, anti-inflammatory, antimicrobial, and antidiabetic properties [60].

Entomophagy is remarkably ingrained in food habits in DRC, seeing that edible insects are considered a valuable traditional food for long and a sustainable source of proteins and vitamins. Study by Nsevolo et al (2021) listed 148 Congolese edible insects identified at species (100 genera, 31 families, and 9 orders dominated by the orders Lepidoptera, Orthoptera, Coleoptera, and Hymenoptera). Insects are part of the regular diet of more than two billion people around the world are delicacies [61]. In the Democratic Republic of the Congo (DRC), caterpillars are the most consumed insects, and they are consumed by more than 70% of the population throughout the year **Table 6**.

Insects are not only valuable sources of lipids, polysaccharides, proteins, and micronutrients but also are sources of bioactive compounds such as phytochemicals with numerous therapeutic properties. Anti-inflammatory, antioxidant, anticancer,

Scientific names	Vernacular names	Antioxidant nutrients	Total Polyphenol (mgGAE/g DW)	Total flavonoids (mgQE/g)	Antioxidant activity IC50 (μg/mL) *		References
					ABTS	DPPH	
Cinabra hyperbius	*Binkubala*	Rutin, Phenolic acid, selenium, Zinc	1.77 ± 0.02	0.13 ± 0.06	10.7 ± 1.4	26.6 ± 2.0	[62]
Cirina forda	*Masese*	Flavonoids, Gallic acid, Zinc	0.22 ± 0.03	5.36 ± 0.56	15.8 ± 1.7	57.0 ± 5.9	[62]
Cirina forda	*Makoso*	Phenolic acid, selenium, Zinc	0.05 ± 0.01	1.38 ± 0.15	16.6 ± 1.4	78.5 ± 1.3	[62]
Cirina forda	*Mingolo*	Phenolic acid, Zinc, Terpenes	0.81 ± 0.09	4.31 ± 0.75	20.7 ± 2.3	68.8 ± 10.4	[62]
Cirina forda	*Massamba*	Phenolic acid, terpenes	0.91 ± 0.09	1.38 ± 0.15	36.4 ± 3.8	73.6 ± 8.6	[62]
Gonimbrasia belina	*Binkubala*	Flavonoids, rutin Phenolic acid, selenium, Zinc	0.23 ± 0.03	2.78 ± 0.24	14.6 ± 1.0	54.3 ± 3.1	[62]
Imbrasia epimethea	*Benkenzo*	Phenolic acid, Zinc, terpenes	0.75 ± 0.07	0.13 ± 0.06	16.6 ± 1.6	43.5 ± 2.1	[62]
Imbrasia sp	*Mboyo*	Phenolic acid, Zinc, terpenoids	1.75 ± 0.07	3.31 ± 0.55	10.8 ± 1.2	21.7 ± 2.4	[62]
Imbrasia runcate	*Mbinzo*	Phenolic acid, Terpenes	1.99 ± 0.05	1.36 ± 0.26	12.1 ± 0.8	52.3 ± 2.7	[62]
Imbrasia runcate	*Mbinzo*	Phenolic acid, Zinc, Terpenoids	2.39 ± 0.05	1.11 ± 0.45	13.3 ± 1.5	26.6 ± 3.0	[62]

Table 6.
Antioxidant activities of insects.

and antimicrobial activities have been reported for the major phenolic compounds found in insects like kaempferol and quercetin when they are directly extracted from plants [62].

9. Conclusion

Oxidative stress, characterized by excessive production of reactive species, is involved in several chronic diseases such as cardiovascular, chronic obstructive pulmonary, sickle cell, chronic kidney, neurodegenerative, and cancer. The data reported in the tables above clearly showed that traditional foods from the biodiversity of the Democratic Republic of Congo are often unvalued, and constitute a potential source of new natural antioxidants. Indeed, the vegetables, mushrooms, yams, nuts, and fruits studied contain polyphenolic compounds, terpenes, and micronutrients, responsible for their antioxidant activities. As Congolese diets, particularly in rural areas, are based on vegetables, such as mushrooms, yams, nuts, and herbs as drinks, there is reason to consider that Congolese traditional foods are a rich source of antioxidant phytonutrients, which brings several health benefits for the population, including the prevention or management of cardiovascular diseases, neurodegenerative disorders, cancer, autoimmune diseases, and diabetes. Considering the importance of oxidative stress on human health, promoting research with a view to valuing the natural antioxidants of biodiversity in Africa, could pave the way toward the discovery of specific natural antioxidant to prevent or treat such and other chronic diseases not transmissible.

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