A Food Pyramid for Sub-Saharan Africa. Health Protection with Mushroom Nutraceuticals

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Abstract

In Sub-Saharan Africa, despite poverty, chronic hunger and food insecurity, traditional eating has been related to positive health outcomes and sustainability. There is little health research on diet quality based on what African people consume. The defining characteristics of the traditional African cuisine are the richness in herbs and spices, fermented foods and beverages, and healthy and whole ingredients used. However, as countries in this region become more economically developed, there is a shift to “modern” occidental foods rich in saturated fats, sugar and sweeteners. As a result, there are increased incidences of previously unreported ailments due to unbalanced diet. The regular practice of infinite international aid to the region to curb food insecurity has been unsustainable, ineffective and with no end in sight. Local increase in production and productivity is imperative. Protein rich foods in dietary guidelines enhance only those of animal or plant sources while rich protein sources such of mushroom, has been absent in these charts. This article considers the valorisation of traditional African foods and the importance of establishing an African Food-Based Dietary Guidelines (AFBDGs), an unprecedented Food Pyramid, along with the added emphasis on the potential of African mushrooms, which may play a role in shielding Sub-Saharan Africans against the side-effects of a western stylish diet and promote health. It enhances the preventive role of mushrooms in viral diseases and other disorders.
Keywords: food pyramid; African foods; mushrooms; viral diseases; nutritional guidelines

1. Introduction

There is little health research on diet quality based on what African people consume. In Sub-Saharan Africa (SSA), comprising some 44 countries, despite poverty, chronic hunger, food insecurity, the trend to modernisation and introduction of new foods and eating choices, traditional eating has prevailed and considered positive in relation to health outcomes and sustainability.

The global food system is very complex and influenced by many different inputs, farming, economics, politics, environment, transport, storage, and consumers. These factors are aggravated in SSA, where notwithstanding its vast arable land is the second world region with the highest prevalence of malnutrition and a net importer of food [1]. The regular practice for the past decades of infinite international aid to the region to curb food insecurity has been unsustainable, ineffective and with no end in sight. However, there is a great potential to increase food production, productivity and reduce poverty and food insecurity in this region.

Malnutrition comprises over-nutrition and under-nutrition (wasting, stunting, and underweight), reflecting disproportions in intake of energy, proteins, essential fatty acids, phytonutrients, vitamins and/or minerals. It is frequent the concurrence of both under-nutrition and over-nutrition in the same population across the life course probably due to inadequate dietary intake or diseases, and inadequate nutrition is still one of SSA’s primary concerns for enhanced human development [2]

In general, despite Africans smoking less and having more physical exercise than in developed countries, when food is available, the African diet rivals the healthy Mediterranean diet. However, in African urban areas, with the growing acceptance of “western” eating habits, one can expect more non-communicable diseases or chronic diseases (e.g. diabetes, cardiopulmonary diseases, cancer) for which African healthcare systems are unprepared [3].
Among many possible initiatives to improve food and nutrition security in SSA, here we approach just two prophylactic steps against the onset of this trend to malnutrition, necessary to be established during childhood:

a) The creation and implementation of an African Food-Based Dietary Guideline that encourages sustainable dietary practices. Ideally, this guideline needs to be specifically designed for each of the main six African regions.

b) The incorporation of African indigenous foods into the existing diet; mushrooms, with proven major health benefits are detailed as functional foods.

Knowledge of what it is eaten is essential to dietetics and food science, as well as for biodiversity, agriculture production, and the food industry.

An overview of the African diet and the importance of establishing Food-Based Dietary Guidelines that apply to SSA are discussed. In addition, as known since ancient civilizations, it is emphasised the role of mushrooms as one of the most health-promoting foods on earth and a possible contributor to the African diet and well-being.

2. The African Diets

The diverse nature of African cooking has fantastic elements of different cultures – Arab, Black African, European, and Asian. Of particular note, African eating and drinking habits are significantly different in each African region.

Presently, there are some five to six main African regions and there are not many studies on food consumption patterns of the African people per country or among the 54 sovereign countries [4]. However, Africans, namely rural people in general, perform more physical exercise in their lives than people in developed countries. In addition, until recently, Africans, namely rural communities, do not eat much ultra-processed foods such as salty fatty packaged snacks, soft fizzy drinks, sweetened breakfast cereals, and instant noodles, which are nutritionally unbalanced [5].

The traditional African diet comprises more wholesome and healthful foods rather than pre-treated food (Figure 1). In general, the defining characteristics of the traditional African cuisine are the richness in herbs and spices, fermented foods and beverages, and healthy and whole ingredients used [6].
In comparison with other continents, very little meat, fish and poultry is generally consumed in Africa [7]. It is considered that people in West Africa (Mali, Chad, Senegal and Sierra Leone) enjoy healthier diets than their counterparts in the United States, the United Kingdom, Japan or Canada [8].

Outlined in Figure 2 are some select African high-nutrition foods “superfoods”, worthy of this title, with high concentrations of essential nutrients such as phytonutrients, vitamins, minerals, enzymes and antioxidants, which have been identified, although no single food holds the key to good health or disease prevention.
Other foodstuffs with good nutrient counts and health properties comprise dark leafy greens, green tea, legumes/pulses, nuts and seeds, yoghurt, garlic, ginger, curcumin, avocado, sweet potatoes, seaweeds, baobab fruits, and mushrooms. Olive oil is also important but in northern Africa where Tunisia and Morocco are considered the largest producers in the world.

Meat, fish, seafood, and traditionally produced fermented dairy products (e.g., yogurt, cromwo, boeber, alouda, amasi, leite azedo) are often used as a garnish, prepared with cooking oil, tomatoes, onions, salt and spices, poured into a mash or porridge made from cereal or cassava flour. Beef, goat, chicken, eggs and mutton are quite expensive in Africa, so these foods are reserved for special days. However, fish and seafood are abundant in coastal regions and in many lakes.

Sustainable diets in Africa, including indigenous and traditional foods (Figure 3), must respect biodiversity and environmental impacts, contributing to production of affordable, nutritive, and social-cultural acceptable foods for present and future generations [9].

![Moringa leaves and tamarind fruit](image)

**Figure 3.** *Moringa leaves and tamarind fruit, widely used as food and for medicinal purpose.*

Most countries periodically review their multi-sectoral nutrition strategies and consider both more effective nutrition-specific intervention approaches (e.g. supplementation, fortification) and/or a shift to actions at the level of underlying causes (e.g. promoting optimal breastfeeding and complementary feeding, diet diversification). We have previously considered the issue of monotonous diet, lack of diversification, and fortification as a matter of business as much as science [10].

3. **African Nutritional Guidelines**
Food-Based Dietary Guidelines are science-based suggestions in the form of instructions for healthy eating. Designed for information to customers and technical advisors, they must be suitable and relevant for each country, culturally appropriate and easy to implement. Moreover, they should be harmonious, comprehensible and unforgettable [11].

The human right to adequate food has cross-sectoral and multi-dimensional impacts but the present global food regulatory framework is confusing and limiting [12]. Many challenges still remain regarding the establishment of dietary guidelines integrating education, agriculture, health, environment and industry.

Nutritional guidelines around the world are presented in different configurations, exhibited as pyramids, plates, baskets, texts, circle graphs, diagrams, and tables, yet similar in terms of content, giving consumers a number of advised food groups and daily servings to maintain optimum health [13].

Many developed countries have established dietary guidelines, but implementation plans are often not comprehensive enough for consumers. In Africa, food-based dietary guidelines have been established in Benin, Kenya, Namibia, Nigeria, Seychelles, Sierra Leone, and South Africa.

The majority of SSA countries did not develop their own food pyramid [14] and, in general, the approach of the legal systems is broadly consistent with the International framework channelled through the Codex Alimentarius Commission since 1963 [15].

In African history, most rural life has been devoted for household production, procurement and preparation of foodstuffs, often low in nutrients, while food scarcity has constituted a major threat to survival. Unless the quality of food (i.e., safety and nutrient composition) that Africans eat is addressed, the continent will not be able to address under-nutrition and obesity-related diseases.

We have enhanced the fact that some 55 major nutrients are reasonably well characterized, and their required levels of intake calculated. However, the subject becomes quite complex when accounting for the active bioavailability of the dietary compound rather than the dose ingested [16]. Furthermore, the amount (over 25,000) of phytonutrients (e.g., flavonoids, phenolic acids, and glucosinolates) naturally occurring in plants are considered “lifespan essentials” for good health although not being
fundamental for growth and development, this being one of the reasons to recommend nine servings of fruits and vegetables a day.

We have reviewed several national dietary guidelines throughout the world and noticed that with few exceptions, fermented foods and mushrooms are generally absent as a recommended category of food for daily intake in Food Guides, reflecting a failure to appreciate the benefits resulting from these foods [13].

Current food systems in African agriculture and animal production, are unsustainable with no diversification and no adequate integration of indigenous vegetables, being one of the greatest current threats to human health [17][18].

Africans eat starchy foods in the form of minimally processed or whole grains, legumes, beans, roots and yams, rather than refined starches and sugary products with the benefit of a high carbohydrate intake supplying 55-75% of total dietary energy [19].

The majority of African cuisines have a different starch base (sorghum, millet, maize, teff, rice, sweet potatoes, cassava, and yams) because they offer lots of calories. Starches are more filling, as they mislead the body and brain into feeling satiated [20]. Usually it is complemented with margarine or oil, supplying an extra source of energy but few essential nutrients where fried onions, garlic and tomatoes make a basic curried sauce [21].

Inadequate nutrition, whether associated with deficiency disorders or chronic diseases, is embedded in impoverishment and neediness [22]. In the poorer regions of SSA, micronutrient malnutrition exists wherever there is undernourishment due to food shortages, and it is likely to become common where diets lack diversity, even in conjunction with sufficient energy intake [23].

Food supplying proteins in dietary guidelines have been organized under the concept of being either animal or plant based while other rich protein sources, i.e., mushroom-derived, has been relatively neglected [24].

Below we propose a graphic design of a general Food Pyramid for Sub-Saharan Africa with inclusion of indigenous products (Figure 4). It is an attempt since a sound or comprehensive African Food Guide Pyramid should be broader and include other information related to food safety, number of meals, amount of (un)refined foodstuffs, processing stages, access to potable water, food traditions, fermented food and beverages,
salt and sugar consumption levels, methods of cooking, sociocultural habits and even creed and religious faiths. To note the specific inclusion of mushrooms as valuable food source of essential nutrients, namely protein and medicinal polysaccharides that have been in the past overlooked in dietary guidelines.

Figure 4. The Sub-Saharan Africa Food Guide Pyramid. There are variations in amounts recommended from different food groups. A “serving size” is a standard amount of a food, such as a cup or a spoon, but they are not fixed recommendations. Recommended to drink a lot of water and teases, exercise physically daily, spare on salt, sweets, candies, processed foods, squash drinks, and fizzy beverages.

The term “portion” means the amount of a food own selected for a refection or snack. A portion size can vary from meal to meal, depending on energy concentration, whereas “serving size” is a measured amount of food usually recommended by the food manufacturer or an external agent. There is room for all foods in a well-balanced, healthy diet, but some should be eaten less often and in smaller portions than others. Appropriate amounts eaten takes practice to land and depends on the individual.

In developing SSA countries, food deficiency distribution varies within its sub-regions and is exacerbated by systemic illness and parasitic diseases, intestinal infections, that decrease digestion, absorption and metabolism of nutrients [25][26].
In SSA it is imperative the promotion of foods with a high ratio of micronutrients to energy content, diversifying food sources, moving away from the concept of food groups and adopt the use of local names for common foods and beverages. Each country, and probably individual region, must design specific Food Based Dietary Guidelines [27][28].

4. African Mushrooms

Mushrooms are vitally important to human life and of primary importance as global decomposers in most ecosystems and have been used in SSA since the Palaeolithic period (7000-9000 BC), where their application has been historically related to spiritualism [29]. Not attempting to be comprehensive here it is highlighted the potential and the current knowledge available on the nutraceutical value of African macrofungi underlining the global application of mushroom as dietary supplements in some major health concerns, also often used for innovative biotechnological, medicinal and ecological applications [30]. It does not underline their application in complementary folk medicine in this part of the world.

The tropical and subtropical regions of SSA are characterized by higher mushroom diversity compared to North Africa. Mushrooms (aboveground macrofungi) and truffles (subterranean macrofungi) are considered valuable foods in many cultures being rich source of different types of essential nutrients, and have been widely studied and reviewed [31][32].

It is clear that there is no single sector or actor that by themselves can establish food and nutrition security but there has to be a well-coordinated effort among them on a cross-sectorial approaches and multi-partner platforms [33]. The poor discovery, identification, and certification of edible and medicinal species of mushrooms in SSA retarded its use. There is a need for cooperative endeavours under a multi-institutional programme to seize the representative macro fungi species of SSA with a view to update their nutritional and health value [34].

Globally there are up to 3 million species of mushrooms, and as there is no single tool for their identification, only some 7% have been accurately classified [35]. There is a broad range of wild edible mushrooms but in Africa many remain poorly identified or unreported but with remarkable use in nutrition, as tonic and medicine [36][37].
Presently in Africa wild mushrooms play a significant role in sustaining their livelihood but there are few ethnomycological reports and research on mushroom genetic resources, cultivation of undomesticated wild mushrooms, protection, and lineage improvement [38].

Mushrooms produce a vast set of extracellular carbohydrate-active enzymes and biological active molecules that degrade very complex compounds such as hemicellulose and lignin. The variety of enzymes is dependent on the habitat and specific substrates, so it differs among mushroom species and home ground [39].

Desert mushroom truffles have been used for thousands of years in Africa, include genera such as *Phaeangium* *Picoa*, *Terfezia*, *Delastreopsis*, *Balstonia*, *Delastria*, *Leucangium*, *Mattirolomyces*, *Tirmania*, and *Tuber* [40], and are of considerable interest for ecological reasons because of the low water input required for cultivation.

Various types of mushrooms and truffles (Figure 5) are considered as natural biota in the North Africa deserts [41][42] and in South Africa and Bostwana [43].

![African desert truffles genus Kalaharituber](image)

**Figure 5.** African desert truffles genus *Kalaharituber*

Mushrooms belonging to species of *Termitomyces*, *Pleurotus*, *Lentinus*, *Lenzites*, *Trametes*, *Ganoderma*, *Pycnoporus*, *Coriolopsis*, and *Calvatia* have been reported to be used in folk medicine in West Africa. Some popular wild edible and medicinal mushrooms in West Africa include *Schizophyllum commune*, *Lactarius* sp., *Chantarellus platyphylus*, *Volvariella volvacea* and *Auricularia auricular-judae* [44][45].

Specific to Africa, there are more than 1000 species from the family Termitidae, constituting 95% of soil insect biomass [46]. Although they are wild, the African mushrooms, and particularly those species associated with termites (*Termitomyces*), are
considered “superior” to all other mushrooms [47]. There are about a 30-40 mushroom species of *Termitomyces* whose cap can reach 1 metre in diameter and most are highly valued as food *(Figure 6)*[48]. On the other hand, mushrooms of the species *Termitomyces, Agaricus, Boletus, Pleurotus, Cantharellus, Macrolepiota, Ganoderma,* and *Geastrum* have been reported in East and South Africa [32].

*Figure 6. African *Termitomyces* mushroom.*

The population on miombo dryland forest ecosystems rely directly on the woodlands for wood energy, food and nutrition. This region extends from East Africa (Burundi, Kenya, Tanzania, Uganda) to the Zambezian region (Angola, DR Congo, Malawi, Mozambique, Zambia, Zimbabwe) where most predominant mushrooms occurring include *Cantharellus* (15 spp.), *Lactarius* (incl. *Lactifluus*) (14 spp.), *Russula* (10 spp.), and *Amanita* (8 spp) [49].

Despite its millennial existence and its empirical knowledge, harvesting wild mushrooms is not a well-known concept in Africa due to the threat of being poisonous and sociological impacts (myth, culture and spirituality) [50][51], while commercial production does exist.

Mushroom cultivation is a lucrative agricultural process to produce proteins requiring compact space, temperate climate, high humidity, and waste organic substrates [52][53].

*Table 1. Comparison of the most consumed mushrooms World-wide and in Africa* [54].
4.1 Bioactive elements of Mushrooms

Mushrooms feed on dead plant material fulfilling an essential role in the carbon cycle while harbouring numerous species with diversity of metabolites of nutraceutical and therapeutic significance [55].

Mushrooms are heterotrophic (do not perform photosynthesis) and reproduce through spores absorbing complex organic compounds from the environment as they are unable to synthesize their own organic matter [56]. The mycelia, which plays important roles as support and absorption of nutrients, rely solely on carbon obtained from other living organisms, i.e., plants, insects, and even other mushrooms, for growth.

There is abundant literature and we have described the nutraceutical value of some edible mushrooms and culinary-medicinal mushrooms, their biomass or extracts, which contain many low molecular bioactive components termed secondary metabolites since they are formed due to the enzymatic resections of primary metabolites (amino acids, sugars, vitamins) [57].

The most common metabolites in mushrooms include polyphenols, phenolic acids, quinones, coumarins, groups of flavonoids, stilbenes, hydrolysable and condensed tannins, terpenes and terpenoids, alkaloids, lectins, sterols, lactones, antibiotics, and metal-chelating agents all of which may activate the cell and humoral immunity hence increasing resistance to disease [58][59][60][61].

Mushrooms are well known to contain different bioactive polyphenolic compounds which act as effective antioxidants based on their excellent ability to scavenge free radicals and act as reducing agents [62]. These biological cell components and secondary metabolites
on large number of mushrooms have been shown to affect the immune system of the human consumer [63][64].

Lignocellulose is the most abundant natural biopolymer on earth and its structure being so complex affects its biodegradation, a rate-limiting steps in the global carbon cycle [65]. Most species of mushrooms synthesize enzymes that may play important functions in the human organism. The vast list of enzymes in mushrooms include hydrolases, (gluco)amylase, pectinase, acid protease, endo-1,4-p-D-glucanase and 3-glucosidase, esterases, phenol oxidases, polyketide synthase, hemicellulases (glucuronoxylanase, arabinogluconoxylanase, and glucomannanase), the ligninolytic system, cell wall lytic enzymes (laminarinase, 1,4-β-D-glucosidase, β-N-acetyl-D-glucosaminidase, α-D-galactosidase, xylanases, β-D-mannosidase, acid phosphatase, laccase, lignin peroxidase, mannanase peroxidase, polygalacturonase-pectinase, ribonuclease and many others [66][67].

Mushrooms can produce a high variety of extracellular enzymes, hidrolases breaking down polyssacharides and a ligninolytic system, which degrades lignin and opens phenyl rings, releasing compounds or remarkable nutritive value [68].

*Hericium* fruiting body contains polyphenol oxidases (PPOs), including tyrosinase and laccase, strong antioxidant substances [69]. By knocking out one of six PPO genes, reducing the enzyme’s activity by 30%, the common white button mushroom (*Agaricus bisporus*) has been modified to resist browning and this is being cultivated and sold without further oversight and even approved by the US government [70]. *Hericium erinaceus* was only recently first reported in temperate forests of North Africa and known to have anti-peptic ulcer activity [71][72][73].

Several studies showed that *Pleurotus eryngii* and *Ganoderma lucidum* can produce laccases and this protein can confer activity against HIV by inhibiting the reverse transcriptase [74][75].

Superoxide dismutase (SOD) is also present in some mushrooms and its important physiological role is in the primary cellular antioxidant defence and its potential therapeutic use [76]. Proteolysis is an essential part of many physiological processes in all biota and basidiomycetes mushrooms are valuable sources of proteases used in defence mechanism of living organisms and in biotechnological processes [77]. Multiple lectins produced by *Flammulina velutipes*, *Pleurotus ostreatus*, *Ganoderma carpense*, and
many others, were shown to have potent inhibitory activity in the cell-free translation system and prevent or retard the spread of malignant cells, through mushroom ribosome inactivating proteins (velutin, α-sarcin, restrictocin, and mitogillin), characterized by the ability to irreversibly block protein synthesis [78][79].

In addition to the presence of enzymes, we have previously discussed [80] the significance of mushroom low-molecular-weight secondary metabolites (e.g. terpenes, steroids, anthraquinones and benzoic acid) which can regulate processes such as cell cycle regulation, apoptosis, autophagy, angiogenesis, metastasis, and signal transduction cascades which are associated with the development of cancer [81][82][61].

Nucleosides and nucleotides are components of native nucleic acids participating in the generation and storage of metabolic energy, synthesis of macromolecules and cell-cell communication through interplay with cell surface protein receptors, which may trigger changes inside the cell and thus the regulation of various physiological processes in the human body via the purinergic and/or pyrimidine receptors.

The purine nucleobases (adenine and guanine), pyrimidine nucleobases (cytosine, uracil, and thymine), nucleosides (uridine, guanosine, adenosine and cytidine), nucleotides and derivatives are common in mushrooms [83], and involved in a variety of enzymatic reactions either as substrates or as cofactors. The significance in the pathophysiology of diseases and therapeutic potentials of pyrimidine scaffolds as valuable medical applications is shown below (Figure 7).
From shiitake mushroom Lentinus edodes, the second most consumed in the world, it can be obtained lentinacin, a nucleoside compound well known to reduce total blood sugar and cholesterol [85]. DNA as well as novel genetically modified foods (GMOs) are composed of the same four nucleotides and consumption is considered safe since the likelihood of transfer and functional integration of DNA from ingested modified food by gut microflora and/or human cells is minimal cause mammalian cells have developed sophisticated methods to excise and destroy exogenous DNA [86]. Nevertheless, there is a practical daily safe limit of nucleic acid intake (ca. 2-4 g) in human adults [87].

5. **Mushroom Nutrition and Host-Microbial Gut Interactions**

The human gut is inhabited by a complex and metabolically active microbial ecosystem, a critical component of digestion and absorption. Some 57% of cells in the body are not human comprising our microbiota, mainly bacteria (60 species), unicellular parasites, yeasts, viruses, protists, fungi and archaea, divided between dominant species, more rare species, and transitory species, essentially residing in the skin and anaerobic bowel and living in harmony with the human hosts.
Collectively, the trillions of microorganisms are called the microbiota, the microbiome being the collection of genomes from all the microbiotas. We know little about the factors framing the origin, evolution, and short- and long-term dynamics of gut microbiota composition and function [88].

Microbiota is established at birth, being a very stable system, while traveling through the birth canal and breastfeeding and this initial microbiota colonization process is crucial for the development [89], being affected if delivery is via caesarean section [90], while mothers’ diet have a stronger association with microbiota than demographic characteristics [91]. At the moment of birth, a new microbial ecosystem is established in the child’s gut, one that resides in that adult's gastrointestinal tract and sets the immune system for future life [92]. The dominant bacterial composition in healthy adults remains relatively stable and is influenced by long-term diet, with mushrooms playing a significant role.

The bacteria species in the colon today are more or less the same as one had when aged six months old [93]. Molecules of the microbiota can mediate the critical balance between health and disease. Microbiota make up only about 1-3 percent of the body's mass, however, genetically the microbiome outnumbers the human genome by more than 150 times. And it is the combination of both human DNA and the microbiome gene complement of the gut, and their metabolisms, which makes us human [94][95][96].

The microbiota is ultimately associated with numerous features of normal animal and human physiology and metabolism, nutritional status, behaviour, and stress response [97]. Additionally, they can be a central or a contributing cause of health and many diseases [98].

Indeed, there is strong interaction between the human gut microbial metabolic pathways and host metabolism [99]. The differences in human genetics and microbiome composition and function, life and culture diversities and variation in environmental exposures affect the nutrient requirements with impact on human mood, distress, melancholy symptoms, cultural and social attitudes [100].

Mushrooms are neither plants nor insects but fungus with a unique role in Nature and Health. Mushrooms live in symbiotic relationship with other organisms (e.g. plants) to produce their own energy while supplying nutrients to the plants, and their role on the ecosystem is singular as they are the sole organisms on Earth performing the elimination
of residues decomposing lingo-cellulosic dead matter and reincorporating on the life cycle [101][102].

The overall balance in the composition of the gut microbial community is important in ensuring homeostasis [103]. The processes through which microbiota drives its beneficial or harmful effects, controlling health, wellness and disease, remain largely unexplained, but include development of signalling molecules and identification of bacterial epitopes by both intestinal epithelial and mucosal immune cells [104][105].

The latest thinking presents this vast army of microbes as a vital component in furnishing and maintaining human health. Such is the microbiota's importance that it is now viewed by scientists as a "separate organ" with its own dynamic metabolic activity [106]. Human gut microbiota is actually directly linked to our brains which is explained by a network of neurons lining our guts that is so extensive some scientists have nicknamed it our "second brain" [107].

The most common anaerobic microorganisms that shapes the host immune system are *Bifidobacteria, Lactobacilli* and *Bacteroides*. The genera, *Prevotella, Ruminococcus* and *Bacteroides (Fibrobacter)*, were shown to have reciprocal patterns of abundance, while little is known about variation across the world [92].

The gut associated lymphoid tissue is critical to maintaining normal digestive processes. Some 80 % of human immune system lies in the gastrointestinal tract and 20 % in the back of the mouth (e.g. amygdala) enhancing the fact that an optimal health starts in the gastrointestinal tract [108]. The connection between the gut, brain, and immune function explains why the intestinal health, food and dietary supplements ingested, can affect mental and neurological health, influencing mood and well-being, stress and anxiety [109].

Improper waste management is a common practice in Africa and has an adverse environmental impact and is unsafe for human health [110] Mushrooms have been used for several thousands of years for medicinal purposes, however their role on the regulation of gut microbiota is a new field and has not been sufficiently studied among the 2,000 species identified as edible [111].

The five key immune responses targeted by mushroom β-glucans involve the production of white blood cells, stem cell mobilization, neutrophil phagocytic capacity, production
of reactive oxygen intermediates and help shift an overstimulated TH2 to a TH1 cell mediated immune response [112][113][114][115].

The array of gut microbiota profiles among SSA populations under different dietary practices and livelihoods is still extensively undetermined.

Food needs to cover the requirements of the human body and of the microbiota and there are significant racial difference in gut, vaginal, and skin microbiomes [116]. In the West people eat diets rich in protein and animal fats, thus have predominantly Bacteroides bacteria, while for those in Africa who consume more carbohydrates, especially rich in fibre, have the *Prevotella* species as the dominant bacteria [117]. In this context, gut microbiota from SSA people have different and specific profile which need to be studied in order to match and determine their nutrient requirements. Since most rural SSA family farmers operate traditional subsistence lifestyles, it is important to evaluate their microbiota profile and role as well as the widespread antibiotic use and general impact of industrialization [118]. This is actually possible by identifying and comparing the microbiome enterotypes in different countries or regions using 16S rRNA sequencing [119].

6. **Anti-inflammatory Role of Mushrooms**

Foods that may originate inflammation comprise processed carbohydrates such as white bread and pastries, fried chips, fizzy drinks, red meat, processed sausages, biscuits, desserts, and margarine. Inflammation is the body immune biological reaction to injury or disease. It is a protective mechanism where the blood flow raises to the area of tissue lesion or infection, a necessary part for recovery [120]. Inflammation is a beneficial reaction because it reveals the challenge of the body to infection; however, it is adverse because it destroys a lot of the fine cells in the process [121]. Evidence supporting the impact of specific foods on inflammation in the body is limited.

Some foods, mushrooms included, have the capacity to suppress inflammation, but it is unclear how often and how much is needed for this benefit. Following an anti-inflammatory diet one can fight off inflammation, however, although there is promising research for the impact of some foods there is no anti-inflammatory miracle food and although diet is crucial, it is not the single factor [122].
African mushrooms such as *Pleurotus tuber-regium*, *Termitomyces* spp., *Pleurotus* spp., and *Agaricus* spp are rich in chitin which can be hydrolysed into glucosamine which is involved in the creation of molecules that protect joints from inflammation [123][124].

Some mushrooms act directly on inflammation. *Cordyceps synensis*, a mushroom that contains a nucleoside compound, cordycepin, that stimulates the production of interleukin 10, an anti-inflammatory cytokine [125].

Wild or cultivated mushrooms, fresh or as dietary supplements, have anti-inflammatory activity occurring through inhibition of NF-κB signalling, a protein complex that controls transcription of DNA, cytokine production and cell survival, and major transcription factor that regulates genes responsible for both the innate and adaptive immune response [126].

*Poria cocos* mushroom also contains triterpenes, which have been shown to improve inflammation and treat tumours [127]. Other mushrooms exert an anti-inflammatory effect less directly, by quenching damaging free radicals and counteracting oxidation. Chaga mushroom (*Inonotus obliquus*), for instance, has antioxidant activity, protecting cells against oxidative damage [128][129]. Oyster mushroom (*Pleurotus ostreatus*) has an antioxidant effect as well [130].

Consuming mushrooms does not necessarily show significant changes on induced inflammatory responses. The result is not surprising since it would certainly be harmful to strongly induce or suppress immune function following ingestion of a commonly consumed food. Mushrooms also have an effect on immune function, but that effect is evident only when the immune system is challenged [131].

Much of the active polysaccharides, water soluble or insoluble, isolated from mushrooms, can be classified as dietary fibres (i.e., β-glucan, xyloglucan, heteroglycan, chitinous substance) and their glycoprotein complexes [132].

The chemical nature of extracted β-glucan varies from different sources. Cereals and other food contain 2.5-4.5% β-glucans but these are not capable to control immune functions. However, mushroom β-glucans, which consist essentially of a (1,3)-β-linked with small numbers of (1,6)-β-linked side chains, can modulate the autoimmune mechanisms [133].
These biological response modifiers (1,3)β-glucans, interact with intestinal cell wall, absorbed into the lymph fluid, where they recruit neutrophils and macrophages and trigger production of cytokines and stimulate immune function [134].

Biomass or an extract derived from the mushroom *Coriolus versicolor*, with potential immunomodulating and antineoplastic activities, has been shown to stimulate the production of lymphocytes and cytokines, such as interferons and interleukins, and may exhibit antioxidant activities [135][136].

Neuroinflammation is a specialized immune response that occurs in the central nervous system, linked to chronic neurodegenerative disorders (e.g. amyotrophic lateral sclerosis, multiple sclerosis, Huntington’s disease, Parkinson’s disease, and particularly Alzheimer’s) negatively affecting mental and physical functioning being characterised by synaptic dysfunction and a gradual loss of neurons from specific regions [137][138].

Mushrooms incorporate ergothioneine, which humans are unable to synthesise, a unique antioxidant, cytoprotective and anti-inflammatory derived from food histidine, but which accumulates to high levels in red blood cells and in many other tissues, functioning both as therapeutic and possibly as preventative agent of several diseases [139][140].

7. **The Antiviral Role of Mushrooms**

New viruses emerge all the time and mushrooms represent a vast source of bioactive molecules, which could potentially be used as antivirals. A virus is an infectious agent metabolically inert made up of a core of genetic material, either DNA or RNA, and an outer protein and lipid shell which can only replicate within a host cell organism. In some virus the nucleocapsid is covered by an external membrane, or envelope, which consists mainly of a phospholipid bilayer but also contains one or two types of virus-encoded glycoproteins [141].

Many of the common edible mushrooms and several mushroom dietary supplements are sources of natural bioactive compounds responsible for prevention and treatment of viral diseases through their improvement of human immunomodulation [142]. Furthermore, numerous previous studies have found many mushrooms exhibiting potential antiviral efficacy [143][144][145].

There are four mushrooms subjected to several clinical studies specifically for fighting viruses [146][147], but the following claims still considered unsubstantiated at least for
Covid-19 prevention and treatment: 1) *Ganoderma*: shown to kill the Influenza A virus, herpes, hepatitis and H1N1 strain of the Flu; 2) *Cordyceps*: fighting the Influenza virus by boosting the body NK cell activity as well as other virus killing cytokines; additionally, it has been shown to decrease inflammation in chronic asthma and other lung diseases; 3) *Maitake*: it has shown to actually stop the replication of the virus which would be very helpful in allowing the body to fight it off without getting to overwhelmed and prevent a lot of excessive damage; additionally, it also shows to boost the body supply of antiviral cytokines; 4) *Shiitake*: ability in stopping the growth of the virus by preventing the entry into the cell; this mushroom has shown to be effective in fighting the herpes simplex virus, hepatitis C virus, HIV and the influenza.

Mushrooms fight viral infections and there are many studies on anti-viral activities of several mushrooms against herpes (HHV-causing skin infections) [148], West Nile (mosquito-borne disease) [149], Orthpoxviruses (variola agent) [150], influenza [151], hepatitis B [152], and human immunodeficiency (HIV) [153]. The most studied mushroom strains for producing antiviral bioactive compounds include *Coriolus versicolor*, *Lentinula edodes*, *Grifola frondosa*, *Ganoderma lucidum*, *Hericium erinaceus*, *Pleurotus ostreatus*, *Cordyceps sinensis*, *Laricifomes officinalis*, *Lenzites betulina*, *Rozites caperata*, *Daedaleopsis confragosa*. [154].

**Figure 8.** Major sites of antiviral drug action through inhibition of proteases necessary for replication, transcription, and maturation of viruses [142].
People cannot avoid harmful germs and viruses but can become ill less often and with shorten periods if the immune system is strong. The objective of enhancing immunity is attractive, but the ability to do so has proved equivocal for several reasons. The immune system is precisely that, a complex network, not a single entity. There are no scientifically proven direct links between various lifestyle changes and enhanced immune function nevertheless one can boost the immune system by sleeping well in order to release protective cytokines, taking zinc [155], vitamins A, C, E [156], curcumin (turmeric) [157] as well as consuming mushroom supplements or fresh mushroom therefore preventing the chance of contracting viral diseases [158].

### 7.1 HIV/AIDS

We have previously reviewed this subject [159] and the pathogenesis of the disease is considered multifactorial. Nutrition is a fundamental part of a comprehensive package of care for people living with HIV/AIDS and mushrooms supply known bioactive molecules that may help patients [135]. To cushion the repercussion of the disease widespread, action taken must integrate all elements involved, including nutritional care [160]. To assess and reduce the severity of the complex interaction between HIV/AIDS and malnutrition have on each other, it is essential to forecast the evolution of the disease and the probability of morbidity and death toll [161].

Mushroom β-glucans increases CD4 cells production and stimulates the immune system macrophages. Even when infected with HIV, the macrophages fight effectively and reduce HIV replication [162]. Several triterpenes from Ganoderma lucidum are active as antiviral agents against human immunodeficiency virus type 1 (HIV-1) [163].

Besides polysaccharides and triterpenoids displaying a variety of medicinal properties, mushrooms contain many antimicrobial factors which include lentinan, ganaderiol-F, ganoderic acid-ß, lucidumol, PSP, coprinol, campestrin, sparassol, armillaric acid, cortinellin and ustilagic acid [164][165][166]. These active compounds fight viruses in two major ways: a) they boost the immune system: directly (specific response) and/or through various factors of humoral and cellular immunity [167]; and b) attack the virus directly, which prevents the proliferation of viruses and can stop viral infections from developing [168].

Direct antiviral effects include inhibition of viral enzymes, synthesis of viral nucleic acids and adsorption or uptake of viruses [169]. Indirect antiviral effects are achieved by
stimulating the immune response against the viral invasion and promoting biochemical factors, such as alkalinity, that discourage viral replication [170]. In many mushrooms, β-glucans, glycoproteins, melanins, terpenoids and nucleosides displayed antiviral activity [171].

The lymphotropic nature of the virus HIV-1, infects humans and the function of the lymph node is disrupted, and production of dendritic cells is increased and accumulation in lymph nodes, presenting exogenous microbial antigens [172].

Drug resistance to anti-HIV drugs is emerging, and many people infected with HIV have serious adverse reactions. Antiviral compounds from mushrooms (e.g., triterpenes, phenolic compounds, ergosterol peroxide, and purine derivatives) are strong biotherapeutics acting directly on the pathways of enzymatic system of the human host, regulating the interactions between viral and components of the human cell [173].

They may also act by inhibiting viral enzymes carried within the capsid and on the viral envelope, while some are only produced in the infected cell [174]. The antiviral compounds of mushrooms also may condition the virus genome intervening on the synthesis pathway of viral nucleic acids and its penetration of viruses into cells [175].

### 7.2 Herpes virus

The Herpes Simplex Virus (HSV-1) co-evolved with humans for thousands of years in a constant, dynamic and endless dance where the pathogen is present at a high prevalence, affecting globally half of the human population [176][177].

While there are more than 100 known herpes viruses two strains occur in most of β-amyloid plaques of Alzheimer’s Disease (AD), being their proteins two-thirds identical suggesting that this common virus may be a possible risk factor for AD showing some evidence that specific viral species directly contribute to a risk of developing AD [178]. The neurotropic virus can either remain in a dormant state, with occasional revitalization events, or eventually originate severe acute encephalitis, marked by aggravated neuroinflammation and extended neuroimmune activation, producing a life-threatening neurological disease [179]. HSVs alters host cell metabolism inducing antiviral mechanisms and reprograms cell death in non-immune cells, capable of inducing apoptosis in immune cells, the death of T cells, while allowing viral replication to occur
in epithelial cells before upring into the neural ganglia producing a latent infection [180].

Antiviral activity of the mycelia of higher mushrooms (Pleurotus ostreatus, Fomes fomentarius, Auriporia aurea, and Coriolus versicolor), against influenza virus type A (serotype H1N1) and herpes simplex virus type 2 (HSV-2) was determined to be effective [181].

7.3 Influenza Virus

Several mushrooms in natural form or as a food supplement are effective on preventing and treating a variety of viruses like the common cold and the flu virus. This is significant if it is considered the highly infectious nature and ability to mutations of these viruses. Boletus edulis, Datronia molis, Calvatia gigantea, Laricifomes officinalis, Suillus luteus, Coriolus versicolor, Lentinus edodes, Lenzites betulina, and Piptoporus betulinus were shown to be effective against the flu-causing influenza viruses [182][183].

7.4 Human papillomaviruses (HPVs)

In Portugal in 2008 the use of Coriolus versicolor biomass supplement for 1 year revealed a great efficacy, whether in the regression of the cervical dysplasia (LSIL), or in the disappearance of the High-Risk HPV. This dietary supplementation showed positive therapeutic impact, either in the reversion of LSIL (with High-Risk HPV+), or in those HSIL patients, who have undergone surgery, but experience continued High Risk HPV viral count [184].

This was subsequently replicated with active hexose correlated compound (AHCC), a fermented extract of cultured Lentinula edodes mycelia, administered for at least 6 months, with a 60% successful elimination of human papillomavirus (HPV) infections in women with positive PAP smears [185]. A recent study involving 42 patients showed that combination of administration of Coriolus versicolor biomass provided positive outcomes in cases of primary or recurrent genital warts [186].

Mushroom in extracts or biomass forms may be given as a complement in aggregation with surgery, chemo- or radiotherapy, with significant influence on NK cell activity when induced by the presence of a viral infection.

7.5 The Novel Coronavirus (SARS-CoV-2)
The interesting thing about this SARS-CoV-2 virus is the symptoms that can range from no conceivable symptoms, all the way to having severe cases of all major symptoms, lower respiratory tract infection with fever, dry cough, and dyspnea, spreading the virus. There are vast number of studies that have been done with mushrooms as a potential antiviral treatment but very few yet specifically with this new virus [187][188].

Recently, *Cordyceps sinensis* and *Cordyceps militaris* were claimed be effective agents for the prevention and treatment of COVID-19 by immunomodulating, reducing the proinflammatory cytokines, preventing lung fibrosis, improving tolerance to hypoxemia and inhibiting the viral enzymes [189].

In Norway *Agaricus blazei*, *Ganoderma lucidum*, *Hericium erinaceus*, and *Grifola frondosa* were considered to have preventive or curative effect against the severe lung inflammation and acute pneumonia that often complicates COVID-19 infection [190].

A recent study in Iraq showed that Ganoderma lucidum uptake on some hematological and immunological response in patients with Covid-19 had a great significant role in helping in the treatment of COVID-19 infections [191].

Mushrooms are the highest dietary source for the unique sulphur-containing antioxidant ergothioneine. This amino acid is a Generally Recognized as Safe (GRAS) product by FDA and gets into the food chain mainly through mushroom consumption. There is a recent study revealing ergothioneine potential beneficial role in SARS-CoV-2 cases [139]

The above claims must not be generalized to the recent SARS-CoV-2 infection [192] and the immediate priority is to harness innate immunity to accelerate early antiviral immune responses.

8. **Antitumour Activity of Mushrooms**

Usually, the causes of cancer are multifactorial, and include genetic, environmental and other risk factors. Recent meta-analysis of 213 studies, including 77 clinical studies, showed that *Ganoderma lucidum* or *Coriolus versicolor* mushrooms enhanced the efficacy and ameliorated their adverse effects, which lead to improved quality of life in cancer patients [193].

Mushroom lectins are a group of proteins/glycoproteins which can possess immunomodulating as well as direct cytotoxic activity toward tumor cell lines. In
mushroom extracts and biomass there are also some anticancer hemolyzing proteins [194], enzyme laccase [195], ribosome inactivating proteins [196], and ubiquitin-conjugated proteins which also display direct cytotoxic activity [197][198].

Polysaccharides of mushrooms have anti-tumour activity, which is associated with the immunostimulatory effect that they can exert, since they activate foreign body reactions from the immune system [199]. This anti-tumour activity is not caused by a direct cytotoxic effect but via activation of the innate immune system of the host. The mechanism of action is related to the presence of pattern recognition receptors that can recognize the polysaccharides as pathogen-associated molecular patterns (PAMPs), due to its high molecular weight [200].

Consequently, pro-inflammatory cytokines are produced in a cascade, including tumour necrosis factor alpha (TNF-α), members of the IL-1 family, which regulate immune homeostasis and the mechanisms against infections, in recognition of foreign cells and tumour cells [201].

Some structures of mushroom β-glucans are better adapted to specific receptors, which suggests a relationship between the structure and antitumour activity of polysaccharides and it was found that, mostly β-1,3-glucan, have the highest antitumour activity [202][203].

Triterpenes, the secondary compounds found in mushrooms, cause tumour cells to self-destruct (apoptosis) [204][205].

Polysaccharide extracts from Hericium erinaceus are active against liver cancer cells in vitro and in vivo [206][207]. The highest consumption of dietary mushrooms, including Agaricus bisporus and Lentinula edodes, is associated with a decreased risk of breast cancer in premenopausal women and postmenopausal women [208].

Maitake mushroom (Grifola frondosa) is one of the most popular edible medicinal mushroom. The natural killer (NK) cells, which have the ability to eliminate target cells without prior immunization, show important role in controlling viral infections and high cytotoxic activity in oncologic patients administered G. frondosa and significantly restrain tumour growth. This is achieved by increased release of TNF-α and IFN-γ from spleen and a significant boost in IFN-γ and TNF-α expressed in NK cells [112]. Ganoderma tsugae is another medicinal mushroom in which sixteen polysaccharides
have been well investigated for anti-tumour effects on Sarcoma 180 (ascitic tumor) in mice [209].

9. **Prebiotic Activity of Mushrooms**

The interest in the gut microbiome and host interaction is increasing. The concept of prebiotic has been updated as “selectively group of nutrients that allow specific changes in the composition and/or activity in the gastrointestinal microbiota providing benefits upon host well-being and health” [210]. Prebiotics act as food for probiotics [211]. Furthermore, some health benefits of prebiotics, such as reducing glucose levels in the blood and improvement of the bowel function, have been medically proven and recognized by health authorities [212].

Endogenous β-glucans show better prebiotic properties than exogenous β-glucans. We have discussed the role of some bacteria Bacteroides (*B. ovatus, B. uniformis, B. capillosus*), *Prevotella, Ruminococcus, E. faecium, Streptococcus*, and *Clostridium* strains that are responsible for degradation of mixed linked β-glucans in the small intestine and in the hind gut [213].

Currently, inulin, fructo-oligosaccharides (FOS), galacto-oligosaccharides (GOS), lactulose and polydextrose are recognized as the well-established prebiotics in the market but there is evidence that β-glucans can also be a source of long chain prebiotics [214]. Extracts of *Pleurotus ostreatus* and *Pleurotus eryngii* have a potential stimulator effect on the growth of probiotic bacteria [215]. Cosmopolitan strains of *Pleurotus* and *Cyclocybe* mushrooms, studied in terms of their prebiotic potential, exhibited a beneficial influence on the composition of gut microbiota of apparently healthy and elderly subjects [216].

The prebiotic effect of mushroom biomass (e.g. *Coriolus versicolor*) on human gut populations of total aerobes and anaerobes showed that dietary mushroom inclusion beneficially affected gut homeostasis performance and exerted changes in intestinal microbial communities [217].

10. **Mushrooms and Neuroimmunology**

When cells generate energy, they use oxygen and yield free radicals as a consequence of ATP generation by the mitochondria, a cell organelle that has a critical role in the development of neurodegenerative disorders [218]. The human body has various
mechanisms to prevent oxidative stress by either yielding inner natural antioxidants (e.g., catalase, enzymes glutathione peroxidase, superoxide dismutase), or provided through foodstuffs and/or dietary supplements [219].

Neurodegeneration caused by disruptions of crucial homeostatic interactions between circulation and the brain may be mediated by microbial products that modulate the gut-brain axis causing neuro-inflammation and neuronal dysfunction [220].

Infection of the central nervous system may have different aetiologies causing inflammation of the brain (encephalitis). Neuro-inflammation can be caused by virus DNA/RNA infection which challenges the host immune system and continued exposure to the inflammatory mediators (e.g., cytokines, chemokines, and ROS) can result in neuronal dysfunction and degeneration [221].

People who incorporate mushrooms into their diets, even in small amounts (more than twice a week), seem to have a lower risk of mild cognitive impairment, usually preceding Alzheimer’s disease [222]. Mushrooms contain many other substances whose exact role in brain health is not yet clear. These include β-glucan polysaccharides, hericenones, erinacines terpenoids, scabronines, isoindolinones, sterols and dictyophorines, a series of compounds that could contribute to the growth of nerve and brain cells [223]

Acetylcholine, a key neurotransmitter and the principal effector of the autonomic nervous system, is responsible for forming new connections and strengthening neural pathways in the brain [224] Hericium erinaceus (also called lion's mane) has been studied as a precursor of acetylcholine which have neuroprotective and anti-neurodegenerative properties. H. erinaceus mycelium shows great promise for the treatment of Alzheimer’s and Parkinson’s diseases [225].

We have previously discussed how abnormal redox homeostasis and oxidative stress causes diverse neuropsychiatric disorders and the immunomodulation role of mushroom biomass of Coriolus versicolor [226]. Presently the interest is to focus on mediator markers of oxidative stress and neuroinflammation in progressive neurodegenerative disorders and distinct configurations of chronic mental illness [227].

Oxidative stress and altered antioxidant systems have been considered an important factor underlying the pathogenesis of Alzheimer’s disease. Brain inflammation has been linked
to many diseases, including amyotrophic lateral sclerosis (ALS), multiple sclerosis (MS), Parkinson’s disease (PD) and, particularly, Alzheimer’s disease (AD) [228].

We have previously discussed [213] the emerging role of lipoxinA4 and inflammasome in neurodegeneration and the potential therapeutic role of mushroom *Coriolus versicolor*. Integrated survival responses exist in the brain, which are under control of redox-dependent genes, called vitagenes, including heat shock proteins (HSPs), sirtuins, thioredoxin and lipoxin A4. Activation of LXA4 signalling and modulation of stress-responsive vitagene proteins could serve as a potential therapeutic target for AD-related inflammation and neurodegenerative damage [229][230].

Emerging mushroom nutraceuticals demonstrate potential as modulators of mitochondrial redox status and energy metabolism, capable of inducing beneficial outcomes on oncology [231]. Mushrooms through their powerful antioxidant characteristics, have the potential to protect neurons in mitochondrial dysfunctions associated aging and neurological disorders [232].

Food and beverages, macronutrients, micronutrients, or supplements, are the main source of energy for humans. Mitochondrial function is dynamic and controls intestinal epithelial stemness, essential characteristic of a stem cell, which is crucial for enabling tissue homeostasis and can be affected by diet as nutritional changes and can impact on mitochondrial structure, and affect energy metabolism [233][234][235].

Anxiety symptoms and disorders, more common than depression, are among the most common primary care challenges in medical practice. There are many evidence-based nutraceuticals and botanicals to treat these conditions. L-theanine is an amino acid (an analogue of amino acids L-glutamate and L-glutamine) found most in tea leaves and in mushrooms. It should be noted that health claims for L-theanine as a supplement are not recognized in the European Union but are approved by the FDA. But mushrooms as food containing L-theanine do not need any approval, becoming a functional food secondary component of medical treatment [236].

The ability of the brain to manage different challenges that arise across lifespan, makes it resilient to cognitive damage preventing dementia. Hippocampal adult neurogenesis has been considered to be a relevant contributor for brain cognitive reserve and brain plasticity [237].
Coriolus versicolor, a common healthful mushroom, has been receiving increasing attention by its antitumoral, anti-inflammatory, antioxidant, antibacterial, and immunomodulatory properties, including in the hippocampus. Our data unveiled a so far unexplored neurogenic potential of Coriolus versicolor supplementation as a possible preventive strategy for different neurological conditions [136][230].

10.1 Role of Mushrooms in Autism

According to the World Health Organization, one child in 160 worldwide suffers from an autism spectrum disorder. Autism is more common in Africa than initially believed and it is a growing global public health concern. Most Africans are largely unaware of autism, a highly heritable neurodevelopmental disorder, often confused with witchcraft, curses or spells and demons, and children with autism in SSA tend to be diagnosed only around age 8, some 4 years later than worldwide.

Many African children with autism, more often boys than girls, are usually hidden away at home and the prevalence is unknown while only few clinicians have the skills or experience to identify the condition. Indeed, maternal and child mental health services have not been a priority since child mortality and malnutrition are more urgent concerns [238][239].

Autism Spectrum Disorder (ASD) is a disorder still very poorly understood, caused by genetic or environmental factors, first recognized in early childhood in the form of a multi organ system disability caused by impaired neurogenesis and apoptosis, impaired synaptogenesis and synaptic pruning or imbalanced excitatory-inhibition system [240].

Few studies with handful cases have been dealt in South Africa, Nigeria, Ethiopia and Kenya fostering the conviction that ASD is more severe in African children than elsewhere with up to 4% of children having the condition [241]. Recent epidemiological studies revealed possible important link between mycotoxin exposure and neurodevelopmental disorders with regard to ASD [242].

We have previously discussed dietary mushrooms and supplements which have specific effects on gastrointestinal inflammation in ASD patients. The most commonly used mushrooms as potent health-boosters, which may bring some hope to autistic children and families, include Chaga (Inonotus obliquus), Reishi (Ganoderma lucidum), Turkey Tail (Coriolus versicolor), Shiitake (Lentinula edodes), Lion’s Mane (Hericium
erinaceus), Cordyceps (Cordyceps militaris), and oyster mushroom (Pleurotus giganteous). They have shown beneficial to symptoms relating to anxiety and depression, related to both autism and attention deficit-hyperactivity disorder (ADHD) [243].

The therapeutic potential of Hericium erinaceus bioactive and bioavailable components that pass the blood-brain barrier has been demonstrated [244]. They act conditioning several functions including the triggering the production of nerve growth factor, the obstruction of the cytotoxicity of extracellular heterogeneous mixture of small peptides plaque deposits, and the shielding against neuron lysis [245].

Unlike neurons, neuroglial cells, the most abundant cell type in the brains, are involved in nutritional homeostasis, detoxification, and aging, providing nutrients and oxygen to neurons, or defend the nervous system from injury, playing a role in neuron synaptic function. Mushrooms could play a protective role against oxidative stress in glial cells. [246].

11. Concluding Remarks

While contemporary dietary patterns and production systems are changing in developed countries, aiming to reduce red meat and processed foods, in SSA priorities are different as traditional eating has been related to positive health outcomes and sustainability.

Mushrooms have distinct nutritional and bioactive profiles and have been absent in all dietary guidelines despite its high biological value of its mycoprotein. There is limited information about the therapeutic and medicinal uses of mushrooms in Africa. Mushrooms complement the human diet with various ingredients not found or deficient in food items of plants and animal origin being considered an ultimate health food and prevention of various human diseases.

Recognizing mushrooms as good sources of nutraceuticals, in nutrient balancing, strengthening human immune system, enhancing natural body resistance, and lowering proneness to disease with little scope of toxicity or overdose, along with their minimal side effects, make them ideal candidates for developing novel dietary supplements and therapies. While mushrooms as food or biomass supplements are fully acceptable in the diet, their extracts must be evaluated differently as they are considered medicinal pharmanutrients.
It should be enhanced that it is unlawful to advertise that a non-food product can prevent, treat, or cure human diseases unless there are competent and reliable scientific evidence, including, when appropriate, well-controlled human clinical studies to evaluate the efficacy and assess their safety in toxicity trials.

Disclosure of Conflicting Interests

All authors declare no conflict of interests.

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