Mushroom Nutrition in Sub-Saharan Africa

Subjects: Nutrition & Dietetics

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The defining characteristics of the traditional Sub-Saharan Africa (SSA) cuisine have been the richness in indigenous foods and ingredients, herbs and spices, fermented foods and beverages, and healthy and whole ingredients used. It is crucial to safeguard the recognized benefits of mainstream traditional foods and ingredients, which gradually eroded in the last decades. Notwithstanding poverty, chronic hunger, malnutrition, and undernourishment in the region, traditional eating habits have been related to positive health outcomes and sustainability. The research prevailed dealing with food availability and access rather than the health, nutrition, and diet quality dimensions of food security based on what people consume per country and on the missing data related to nutrient composition of indigenous foods. As countries become more economically developed, they shift to “modern” occidental foods rich in saturated fats, salt, sugar, fizzy beverages, and sweeteners. As a result, there are increased incidences of previously unreported ailments due to an unbalanced diet. Protein-rich foods in dietary guidelines enhance only those of animal or plant sources, while rich protein sources such as mushrooms have been absent in these charts, even in developed countries.

food insecurity mushroom nutrition poverty health promotion health foods

1. Introduction

The basic human Right to Food, a 73-year-old commitment of all countries, should have guaranteed each living person to be exempt from hunger, which is mainly generated and perpetuated by human decisions and the dependency on international trade agreements. Universally, the concept has evolved to Right of Adequate Food interlinking policies on agriculture and nutrient requirements with fields such as environment, climate, energy, education, social–economy, and marketing.

Despite regular and record numbers of national and international campaigns, programmes, initiatives, global development goals, universal declarations, technical and scientific articles, and books, Sub-Saharan Africa stands as the world’s most food-insecure region. Albeit advances, hunger, food insecurity, and under nutrition still prevail as a serious hazard and the United Nations Zero Hunger Challenge by 2030 is in doubt and probably unachievable.

Agriculture and Fisheries, and associated sectors, are the main sectors of occupation for the majority of African people. Agriculture, sea, and river resources are the impelling cause of economic reform in Africa, since it bears the world’s largest unfarmed arable land and marine assets, employing a large fraction of the population [1]. Nevertheless, SSA is a net food importer that is dependent on most agricultural and agro-food sectors, namely

maize, rice, and wheat. This situation was aggravated in the last four decades, mainly due to rapid population growth, persistent economic inequality, climate change threats, and even claims of the legacy of colonialism.

In order to obtain a SSA food sovereignty, further to the general need to increase the production and productivity of cereals, untapped traditional and native food crops with expected nutritional attributes remain to be extensively researched and considered, having massive potential to improve the agri-food and fisheries' value chains [2].

Smallholder farmers and fisherman, with a valuable central role to play, have been struggling on a subsistence level often with no community-control and biodiversity-based food systems. There is no panacea for these issues, and the first movement must be on investments in agricultural and fisheries infrastructures and extension services, as smallholders are key actors in food security and in poverty reduction [3].

The leverage of agriculture for food and nutrition security is a means to improve human health and dietary patterns toward increasing agricultural diversity and ensure a balanced diet. However, there is little health research on diet quality based on what African people consume, and a rigorous evaluation of for example universal micronutrient supplementation effects from international aid programmes is extremely rare.

The practice for the past decades of vast and well-intended international aid, even from the United Nations WFP, to the region to curb food insecurity has been unsustainable, ineffective, with unintended consequences and may even ultimately cause harm. It is essential to link aid effectiveness to catalyse development strategies with a longer-term focus.

In SSA, comprising some 44 countries, despite poverty, chronic hunger, food insecurity, movement to renewal, and the arrival of new foods and eating habits, the traditional food choices have luckily prevailed and been considered beneficial in relation to health outcomes and sustainability [4].

However, it is changing, since with no trade agreements, many international organizations and food companies dump their products to gain market share in SSA. Since the 1960s, the African people have consumed increasing amounts of processed food.

The global food system is very complex and influenced by many different inputs, including farming, economics, politics, environment, transport, storage, and consumers; it must entail long-term dimensions on sustainability. These factors are aggravated in SSA, the second world region with the highest prevalence of under-nutrition as well as inadequate incomes or other resources.

Malnutrition is still one of SSA's primary concerns for enhanced human development. Due to inadequate dietary intake and lack of nutritional knowledge, there is a frequent concurrence of both under-nutrition and over-nutrition in the same population across the life course probably due to unbalanced diets or diseases [5]. There are multiple reasons for malnutrition and promoting actions must be multi-sectorial, although quite complex to coordinate.

In general, despite indications that Africans are smoking less and having more physical exercise than in developed countries, when food is available, the African diet rivals the healthy Mediterranean diet. African cuisine is a healthy way of cooking and may become an example if food diversity is enhanced. 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 [6].

Among many possible initiatives to improve food and nutrition security in SSA, it is important to identify consumer habits in each region. Ideally, a guideline needs to be specifically designed for each of the main six African regions or even per country. The incorporation of African indigenous foods into the existing diet must be incentivized. African “superfoods” and other functional foods and beverages, with traditionally proven major health benefits, should be encouraged.

Knowledge about what is eaten is essential to dietetics and food science as well as for biodiversity, agriculture production, and the food industry. Food pattern recommendations usually limit the intake of salt, sugar, and saturated fats and are normally derived from established dietary guidelines. While these have been well structured in developed countries [7], only very few SSA countries have achieved this stage.

An overview of the African foods and ingredients and the importance of establishing national dietary guidelines that apply to each country or region are discussed. Contrary to what is known from ancient Asian civilizations, the ethnomycological knowledge of useful African mushrooms is scant. Furthermore, gut microbiota from SSA people have different and specific profiles, which need to be studied in order to match and determine their nutrient requirements. Since most rural SSA small farmers operate traditional subsistence lifestyles, it is important to evaluate their microbiota profile and role as well as the widespread antibiotic use [8].

2. Anti-Inflammatory Role of Mushrooms

Inflammation, the cornerstone of pathology, is a complex protective mechanism where the blood flow raises to the area of tissue lesion or infection, which is a necessary part for recovery [9]. Inflammation a healing restorative process; however, it may be adverse also, because it destroys a lot of the fine cells in the process [10].

Based on the need to develop novel therapies, researchers have sought evidence supporting the impact of specific foods on inflammation in the body. 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.

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 [11].

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 the 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 [12].

Common African mushrooms such as *Pleurotus tuber-regium*, *Termitomyces* spp., *Pleurotus* spp., and *Agaricus* spp. are rich in chitin, which can be hydrolyzed into glucosamine, which is involved in the creation of molecules that protect joints from inflammation [13][14].

Some mushrooms act directly on inflammation. *Cordyceps synensis*, a mushroom that is abundant and diverse in humid temperate and tropical forests at high altitude, not yet reported in SSA, contains a nucleoside compound, cordycepin, that stimulates the production of interleukin 10, an anti-inflammatory cytokine [15].

Wild or cultivated mushrooms, fresh or as dietary supplements, have anti-inflammatory activity occurring through inhibition of the NF-κB signalling pathway, which is a protein complex that controls cytokine production and cell survival, and it is a major transcription factor that regulates genes responsible for both the innate and adaptive immune response [16].

Poria cocos mushrooms also contain triterpenes, which have been shown to improve inflammation and treat tumors [17]. Other mushrooms exert an anti-inflammatory effect less directly by quenching damaging free radicals and counteracting oxidation. For instance, Chaga mushrooms (*Inonotus obliquus*) have antioxidant activity, protecting cells against oxidative damage [18][19]. Oyster mushrooms (*Pleurotus ostreatus*) have an antioxidant effect as well [20].

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 [21].

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 of controlling 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 [22].

These biological response modifiers (1,3)-β-glucans interact with the intestinal cell wall and are absorbed into the lymph fluid, where they recruit neutrophils and macrophages and trigger the production of cytokines and stimulate immune function (Figure 1) [23].

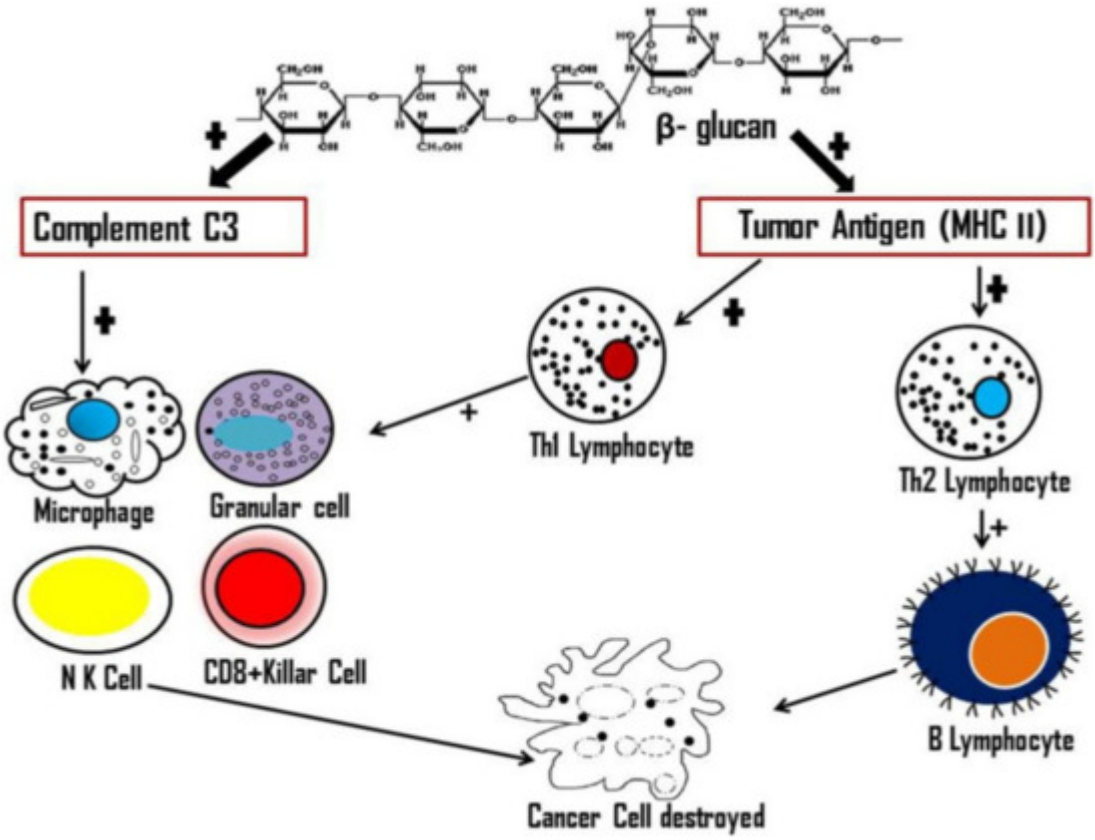

Figure 1. Mechanism of antitumor activity of β-glucan bioactive compound [24]. Normally, tumor cells do not express major histocompatibility complex (MHC-II) genes. NK = natural killer. Complement C3 = C3 (C3 deficiency are susceptible to bacterial infection).

Dietary supplements as biomass or extracts derived from the mushroom *Coriolus versicolor* are not foods; they have potential immunomodulating and antineoplastic activities, and they were shown to stimulate the production of lymphocytes and cytokines, such as interferons and interleukins, and they may exhibit antioxidant activities [25][26].

Neuroinflammation is a specialized immune response that occurs in the central nervous system, and it is 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 characterized by synaptic dysfunction and a gradual loss of neurons from specific regions [27][28].

Mushrooms incorporate ergothioneine, which humans are unable to synthesize, 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 a therapeutic and possibly as a preventative agent of several diseases [29][30].

3. The Antiviral Role of Mushrooms

New viruses emerge all the time and can be serious threats to public health. Recently, it was reviewed how mushrooms represent a vast source of bioactive molecules, which could potentially be used as antivirals [31].

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 using the host cell mechanisms [31].

Many of the common edible mushrooms and several non-edible mushroom dietary supplements are sources of natural bioactive compounds responsible for the prevention and treatment of viral diseases through their improvement of human immunomodulation (Figure 2) [32]. Numerous previous studies have demonstrated mushrooms as exhibitors of potential antiviral efficacy [33][34][35].

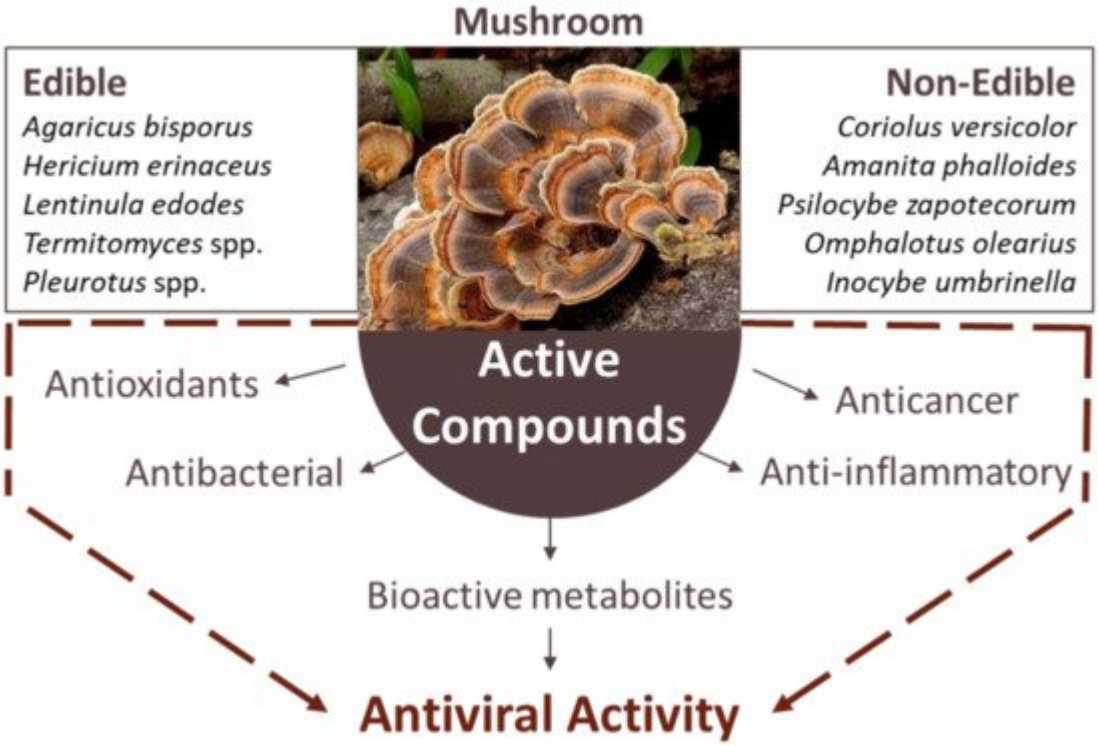

Figure 2. With over 400 bioactive compounds, mushrooms have shown a number of antiviral effects, and used as dietary supplements, functional food or medicinal products. They act by blocking virus entry into the cell, by inducing lysis of virus infected cells through activation of NK, CD8+ and T cells, by anti-neuroaminidase increased activity, and by innate immune support.

There are four mushrooms subjected to several clinical studies specifically for fighting viruses [36][37], but the following claims are 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 too overwhelmed and preventing a lot of excessive damage; additionally, it is also shown to boost the body supply of antiviral cytokines; (4) Shiitake: ability to stop 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 antiviral activities of several mushrooms against herpes (HHV-causing skin infections) [38], West Nile (mosquito-borne disease) [39], Orthpoxviruses (variola agent) [40], influenza [41], hepatitis B [42], and human immunodeficiency (HIV) [43]. 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*, and *Daedaleopsis confragosa* [44].

People cannot avoid harmful bacteria and viruses, but they can become ill less often and with shorter 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 for example sleeping well in order to release protective cytokines, taking zinc [45], vitamins A, C, and E [46], curcumin (turmeric) [47], as well as consuming mushroom dietary supplements or fresh mushroom, therefore preventing the chance of contracting viral diseases [48].

3.1. HIV/AIDS

We have previously reviewed this subject [49], 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 bioactive molecules that may help patients [25]. To cushion the repercussion of the disease, widespread, action taken must integrate all elements involved, including nutritional care [50]. To assess and reduce the severity of the complex interaction that 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 [51].

Mushroom β-glucans increase CD4 cells production and stimulate the immune system macrophages. Even when infected with HIV, the macrophages fight effectively and reduce HIV replication [52]. Several triterpenes from *Ganoderma lucidum* are active as antiviral agents against human immunodeficiency virus type 1 (HIV-1) [53].

In addition to polysaccharides and triterpenoids displaying a variety of medicinal properties, mushrooms contain many antimicrobial factors, which include lentinan, ganaderiol-F, ganoderic acid-β, lucidumol, PSP, coprinol, campestrin, sparassol, armillaric acid, cortinellin, and ustilagic acid [54][55][56]. 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 [57]; and (b) they attack the virus directly, which prevents the proliferation of viruses and can stop viral infections from developing [58].

Direct antiviral effects include inhibition of viral enzymes, synthesis of viral nucleic acids, and adsorption or uptake of viruses [59]. Indirect antiviral effects are achieved by stimulating the immune response against the viral invasion

and promoting biochemical factors, such as alkalinity, which discourage viral replication [60]. In many mushrooms, β-glucans, glycoproteins, melanins, terpenoids, and nucleosides displayed antiviral activity [61].

Through the lymphotropic nature of the virus HIV-1, it infects humans, and the function of the lymph node is disrupted, the production of dendritic cells is increased, and there is accumulation in lymph nodes, presenting exogenous microbial antigens [62].

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 [63].

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 [64]. 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 [65].

3.2. 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 [66][67].

While there are more than 100 known herpes viruses, two strains occur in most β-amyloid plaques of Alzheimer's Disease (AD), as their proteins are 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 [68].

The neurotropic virus can either remain in a dormant state, with occasional revitalization events, or eventually originate severe acute encephalitis, which is marked by aggravated neuroinflammation and extended neuroimmune activation, producing a life-threatening neurological disease [69]. HSVs also alter host cell metabolism, inducing antiviral mechanisms and reprogramming cell death in non-immune cells; they are also capable of inducing apoptosis in immune cells and the death of T cells, while allowing viral replication to occur in epithelial cells before uprising into the neural ganglia, producing a latent infection [70].

Antiviral activity of the mycelia of higher mushrooms (*Pleurotus ostreatus*, *Fomes fomentarius*, *Auriporia aurea*, *Polyporus squamosus*, and *Coriolus versicolor*) against influenza virus type A (serotype H1N1) and herpes simplex virus type 2 (HSV-2) was determined to be effective [71]. They occur in SSA but may not be edible due to their texture and bitter taste but used as medicinal and functional properties [72].

3.3. Influenza Virus

Several mushrooms in natural form or as a food supplement are effective on preventing and treating a variety of viruses such as the common cold and the flu virus. This is significant upon considering the highly infectious nature

and ability of these viruses to mutate. *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 [31][73]

3.4. Human Papillomaviruses (HPVs)

The use of *Coriolus versicolor* biomass supplement in women 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 the High-Risk HPV viral count continued to increase [74].

This was subsequently replicated with active hexose correlated compound (AHCC), which is a fermented extract of cultured *Lentinula edodes* mycelia that is administered for at least 6 months with a 60% successful elimination of human papillomavirus (HPV) infections in women with positive PAP smears [75]. A recent study involving 42 patients showed that a combination of administration of *Coriolus versicolor* biomass provided positive outcomes in cases of primary or recurrent genital warts [76].

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

3.5. The Novel Coronavirus (SARS-CoV-2)

Currently, no specific treatment has been identified for COVID-19. The interesting thing about this SARS-CoV-2 virus is the symptoms, which 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 dyspnoea, spreading the virus. There are a vast number of studies that have been done with mushrooms as a potential antiviral treatment but very few yet specifically with this new virus [77]

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 [78]. *Lentinus edodes*, *Grifola frondosa*, and *Inonotus obliquus* are considered to have therapeutic potential as a natural antiviral treatment against SARS-COV-2, opening the research into this field.

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 [79].

A recent study in Iraq showed that *Ganoderma lucidum* uptake on some hematological and immunological response in patients with Covid-19 had a significant role in helping in the treatment of COVID-19 infections [80].

Mushrooms are the highest dietary source for the unique sulfur-containing antioxidant ergotheionine. This amino acid is a Generally Recognized as Safe (GRAS) product by the FDA and gets into the food chain mainly through mushroom consumption. There is a recent study revealing ergotheionine's potentially beneficial role in SARS-CoV-2 cases [28].

The above claims must not be generalized to the recent SARS-CoV-2 infection [81], and the immediate priority is to harness innate immunity to accelerate early antiviral immune responses.

4. Antitumour Activity of Mushrooms

Usually, the causes of cancer are multifactorial, and they include genetic, environmental, and other risk factors. A 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 an improved quality of life in cancer patients [23][82].

Mushroom lectins are a group of proteins/glycoproteins that can possess immunomodulating as well as direct cytotoxic activity toward tumour cell lines. In mushroom extracts and biomass, there are also some anticancer haemolysing proteins [83], enzyme laccase [84], ribosome-inactivating proteins [85], and ubiquitin-conjugated proteins, which also display direct cytotoxic activity [86][87].

Polysaccharides of mushrooms have antitumor activity, which is associated with the immunostimulatory effect that they can exert, since they activate foreign body reactions from the immune system [88]. This antitumor 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 [89].

Consequently, proinflammatory cytokines are produced in a cascade, including tumour necrosis factor alpha (TNF-α), which are members of the IL-1 family that regulate immune homeostasis and the mechanisms against infections in recognition of foreign cells and tumour cells [90].

Some structures of mushroom β-glucans are better adapted to specific receptors, which suggests a relationship between the structure and antitumor activity of polysaccharides, and it was found that mostly β-1,3-glucans have the highest antitumor activity [91][92]. Triterpenes, the secondary compounds found in mushrooms, cause tumour cells to self-destruct (apoptosis) [93][94].

Polysaccharide extracts from *Hericium erinaceus* are active against liver cancer cells in vitro and in vivo [95][96]. 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 [97].

Maitake mushroom (*Grifola frondosa*) is one of the most popular edible medicinal mushrooms. The natural killer (NK) cells, which have the ability to eliminate target cells without prior immunization, show an important role in controlling viral infections and high cytotoxic activity in oncologic patients administered *G. frondosa*, and they significantly restrain tumour growth. This is achieved by an increased release of TNF-α and IFN-γ from the spleen and a significant boost in IFN-γ and TNF-α expressed in NK cells [98].

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