Asian Journal of Biological Sciences

OPEN ACCESS

Mineral Element Enrichment of Mushrooms for the Production of More Effective Functional Foods

V.O. Oyetayo

Department of Microbiology, Federal University of Technology, Akure, Nigeria

ABSTRACT

In the last three decades, human awareness of the promotion of good health through dietary intervention had increased. Hence, there has been advocacy for the promotion and consumption of health-enhancing foods referred to as functional foods. Myconutrients and chemicals obtained mainly from higher fungi have also received attention as sources of bioactive compounds that can serve as functional foods. Moreover, the importance of mineral elements in our diet for the maintenance of human health cannot be over-emphasized. These elements are responsible for a lot of chemical and electrical processes that enhance the stable homeostatic physiological state in the body and their absence normally results in deficiency diseases. These processes are highly specified and specialized and the human body can only function properly if the accurate balance of minerals and other elements is continually being supplied to look after our system. Most staple foods consumed by humans are lacking in one essential mineral element or the other. It is therefore expedient to find a way to remedy this. Edible and medicinal mushrooms that can easily absorb minerals and can bio-accumulate them as functional organic compounds during growth can therefore be used as a vehicle to supply these mineral elements that are not in adequate amounts in our diet. This will certainly be a definite strategy to solve the problem of mineral malnutrition. Some of these essential elements are selenium, iron, zinc, calcium and so on. This paper, therefore, highlights the potential of mushrooms as a hydra-headed vehicle for the supply of mycoactive compounds and essential minerals in our diets as a means of promoting human health.

KEYWORDS

Health, enhancing, functional foods, strategy, mineral elements, enrichment

INTRODUCTION

One of the key concerns of man is the maintenance of good health. It is popularly said that health is wealth. Food, which is one of the necessities of life outside shelter and cloth, is very essential in the maintenance of good health. It is needed to achieve a stable homeostatic physiological status in humans to prevent diseases and ailments. A diseased state is often described as a deviation from the normal physiological state and food with the required healthy constituents has been found to help in maintaining this stable physiological state. Food has been considered the major factor in maintaining well-being and

ISSN: 1996-3351 (Print)
https://doi.org/10.3923/ajbs.2023.18.29

Received: 27 Jul. 2022
Accepted: 09 Sep. 2022
Published: 31 Mar. 2023

health from the beginning of human history[1]. Hippocrates, who was considered the father of Western medicine, stated as far back as 400 BC, “Let thy food be thy medicine and thy medicine be thy food”. In essence, Hippocrates recognized the relationship between food and good health. Despite the submission of Hippocrates, foods were only recognized as being nutritious based on their content of essential nutrients such as fats, protein, carbohydrates, minerals and vitamins.

In the last three decades, growing scientific evidence has demonstrated that other bioactive food constituents, often referred to as phytochemicals and zoochemical, may provide a health benefit beyond basic nutrition and help prevent chronic diseases like cardiovascular disease, diabetes, cancer and osteoporosis among others. These foods that can enhance good health are referred to as functional foods in Europe while, America adopted the term Nutraceuticals. The word functional foods and nutraceuticals are often used interchangeably. However, Cencic and Chingwaru[2] differentiated between the two terms by stating that functional food provides the body with the required amount of vitamins, fats, proteins, carbohydrates, minerals etc, needed for its healthy survival while nutraceuticals on the other hand help in the prevention and treatment of diseases apart from preventing anaemia.

Functional food or medicinal food is any fresh or processed food claimed to have a health-promoting and/or disease-preventing property beyond the basic nutritional function of supplying nutrients[3]. Functional food must be food, not a drug. Beneficial effects should be obtained by consuming normal amounts of functional food within the ‘normal’ diet. The ultimate goal of the scientific community and food industry is to develop functional foods for improving life quality[4]. Functional foods are therefore used to enhance certain physiological functions and to prevent or even cure diseases[5]. The term ‘functional food’ was coined in Japan in the 1980s and refers to processed foods containing ingredients that aid specific body functions, in addition to being nutritious[6]. Currently, there is no universally accepted term for functional foods. A variety of terms have appeared worldwide such as nutraceuticals, medifoods, vitafoods, custom foods, designer foods and the more traditional dietary supplements and fortified foods. The Japanese were the first to observe that food could have a role beyond gastronomic pleasure and energy and nutrient supply to the human organism. Following this observation, Japan is the country where most functional foods are on the market and the first country to legislate these products in the FOSHU (Foods of Specified Health Use) legislation. However, functional foods are generally considered as those foods which are intended to be consumed as part of the normal diet and that contain biologically active components which offer the potential of enhanced health or reduced risk of disease[7]. Examples of functional foods include foods that contain specific minerals, vitamins, fatty acids or dietary fibre, foods with added biologically active substances such as phytochemicals or other antioxidants and probiotics that have live benefits. According to this definition, unmodified whole foods such as fruits and vegetables represent the simplest form of functional food. Plant foods such as broccoli, carrots or tomatoes are rich in such physiologically active components as sulforaphane, beta carotene and lycopene, respectively which made them be physiologically active when consumed.

According to Hassler[6], the present interest and developments in functional foods stem from:

- Increased scientific understanding of the importance of food constituents and properties for health
- Opportunities for the food industry to develop, on this basis, foods with added value that the consumer is willing to pay for and
- New possibilities to increase consumers’ health and well-being and to help combat current diet-related diseases

Functional foods in the last three decades in the western world has be a new revolution and there is a rapid growth of functional food industries while in the orient, functional foods have been a part of the culture for centuries. In Traditional Chinese Medicine, foods that have medicinal effects have been documented since at least 1000 BC. From ancient times, the Chinese have believed that foods have both preventive and therapeutic effects and are an integral part of health, a view that is now being increasingly recognized around the world[8].

Mushrooms are known to be pharmacologically active; hence they are important in food and medicine. Edible mushrooms are known to be a source of healthy foods. They contain high-quality digestible protein that varied between (10-40%), carbohydrates (3-21%) and dietary fibre (3-35%) on a dry weight basis depending on the species[9]. Pharmacologically, the activities of mushrooms have been linked to the bioactive compounds present in them. The health-promoting properties of edible and medicinal mushrooms have been associated with the presence of numerous bioactive compounds present in them. Major bioactive compounds found in mushrooms include polysaccharides, proteins, terpenes, phenolic compounds and unsaturated fatty acids and many other substances of different origins[10,11]. The fruit bodies and the mycelium of some medicinal mushrooms are known to contain compounds with wide-ranging medicinal properties[12]. The use of mushrooms as a healthy food has been enhanced based on their rich proteins and minerals and poor calories and fat[13]. Health-promoting properties such as antioxidant, antimicrobial, anticancer, cholesterol-lowering, immunostimulatory and many others had been associated with the consumption of mushroom[14-16].

Mushrooms can also absorb mineral elements and can bioaccumulate them as functional organic compounds during growth. Mineral nutrients are indispensable to the maintenance of life. These elements are very important for cell functions at biological, chemical and molecular levels[17]. Human nutritional requirements demand at least 23 mineral elements. Some of these essential elements are selenium, iron, zinc, calcium and so on. This article, therefore, focused on the potential of using mushrooms as a hydra-headed functional food for the supply of myconutraceuticals and essential mineral elements in our diets as a means of promoting human health.

Mineral elements and their importance in health promotion: The daily intake of several minerals is a necessity for the continued basic functioning of the human body. Hence, human needs both macronutrients and micronutrients for the maintenance of good health; however, most people are aware of the importance of macronutrients such as carbohydrates, fats, proteins and vitamins in health promotion while no cognizance is taken of micronutrients. The body mass of the man is made up of 98% of nine nonmetallic elements. The absence of these metals in adequate amounts can affect the metabolic process which can lead to disease. Etiopathogenesis of many nutritional disorders has also been linked with interactions among these trace elements though they constitute only 0.02% of the body weight, they play significant roles as active co-enzymes or trace bioactive substances[17,18]. Volumes of scientific data from physiologic investigations have revealed that inadequate consumption of these micronutrients (minerals and trace elements) can affect the optimal absorption and utilization of other nutrients to work effectively in the body. Mineral elements are needed in adequate amounts to regulate important metabolic and structural functions in the human body. Mineral elements which constitute a very small portion of the body weight are very important in all activities of the body. They are essential participants in every metabolic process carried on by the body. It has been observed that humans required more than 22 mineral elements which can be supplied by an appropriate diet[19]. A balanced diet must of necessity contain these required mineral elements in adequate amounts.

Mineral elements are categorized as micro- or macro-minerals based on the amount needed in the human diet to maintain good nutrition. Microelements or trace elements are required in amounts as low as a few milligrams or less per day. Other microelements are required in lesser amounts as low as micrograms per day. These are referred to as ultra-trace elements. Common examples of microelements are iron, zinc, copper, manganese, selenium, iodine, chromium and molybdenum. On the other hand, macroelements are mineral elements required in hundreds of milligrams to several grams per day. Some examples of macroelements are calcium, phosphorus, magnesium, potassium and so on. The importance of some of these mineral elements is individually stated below.

Copper (Cu): Copper is a micronutrient needed at milligrams less per day. The daily requirement is about 2-5 mg out of which about 50% is absorbed from the Gastrointestinal Tract (GIT)[17]. Copper (Cu) is an essential trace element in both humans and animals. It is needed only in trace amounts, the human body contains approximately 100 mg Cu. It is also involved in a myriad of biological processes such as antioxidant defense, neuropeptide synthesis and immune function[20,21]. Copper plays a significant role in human metabolism because it allows many critical enzymes to function properly[22]. The solubility of copper is more pronounced in acidic conditions where copper ions are incorporated into the food chain in the cupric or cuprous form[17]. In the human body, copper accumulates in the liver, brain and kidney. Over 90% of plasma copper is associated with ceruloplasmin and 60% of Red Blood Cell (RBC) is bound to superoxide dismutase. Copper is required for the normal growth and health of the human body. It plays a role in the formation of connective tissue and the normal functioning of muscles and the immune and nervous systems[17]. Copper and iron are required for the formation of red blood cells. Copper also influences the functioning of the heart and arteries, helps prevent bone defects such as osteoporosis and osteoarthritis and promotes healthy connective tissues[23]. Copper is involved in cell metabolism and is a part of various enzymes such as tyrosinase, uricase and cytochrome oxidase, which are mainly concerned with oxidation reactions[17].

Bost *et al.*[23] reported that copper level in foodstuff is affected by factors such as soil Cu concentration, slurry/manure spreading and use of Cu compounds as microbiocides on crops. Moreover, copper content in cereals, fruit and vegetables and, in meat and animal products is also affected by copper emissions from smelting and casting industries[24,25]. Food groups such as offal and nuts are rich in copper while to a lesser extent cereals and fruit are also good sources of Cu. However, milk and dairy products have been reported to contain low amounts of Cu[26].

Copper deficiency in our diet can lead to anaemia, growth retardation, defective keratinization and pigmentation of hair, hypothermia, mental retardation, changes in the skeletal system and degenerative changes in aortic elastin. On the other hand, when copper is in excess in our diet or through other sources, it can produce nausea, vomiting, diarrhoea, profuse sweating and renal dysfunction[17]. The following had been identified as the symptoms of copper deficiency: hypochromic anaemia, neutropenia, hypopigmentation of hair and skin, abnormal bone formation with skeletal fragility and osteoporosis, joint pain, lowered immunity, vascular abnormalities and uncrimped or steely hair[27].

Zinc (Zn): Zinc is a trace mineral element that played important role in gene expression, cell development and replication[28]. It is therefore essential to all forms of life. Zinc is needed for growth and must be in sufficient amounts in tissues such as the immune and gastrointestinal tract that are involved in rapid cellular differentiation[29]. The average body content of zinc in an adult is 2-3 g and the average daily requirement is 15-20 mg/day[17]. The level of zinc intracellularly is about 99% while the rest is in the plasma. It is required for the catalytic activity of approximately 100 enzymes[17].

Zinc is also required for a proper sense of taste and smell. The body does not possess a specialized zinc storage system; hence a daily intake is required for the body to maintain a steady state[30]. Zinc is found in abundance and the absorbable form in the organs and flesh of mammals, fowl, fish and crustaceans since these foods do not contain phytate that can chelate it. The content of zinc in fruits and vegetables is not high except for spinach which contains a fairly high zinc density[29]. Zinc deficiency is characterized by growth retardation, loss of appetite and impaired immune function[31,32]. Summarily, zinc is essential for body growth, maturation and development as well as tissue repair and resistance to disease. It is important for children and the aged. Deficiency of zinc in the diet of children can result in reduced growth, while in adults it can lead to reduced infection and delayed wound healing in people of all ages. The body needs 15.0 milligrams of zinc per day.

Magnesium (Mg): Magnesium is a macromineral element that is very essential to the proper functioning of the body. It is a vital nutrient and is the active mineral in at least 300 known enzymes in the human body[33]. The Recommended Daily Intake (RDI) for magnesium for adult males is 400 mg/day with slightly lower for children and women. Magnesium is required to help the body do the following: Produce energy, protein synthesis, muscle and nerve function control, blood glucose control and blood pressure regulation.

Magnesium plays a very important role in the electrical functions of the heart to keep a regular beat[33]. Other functions of magnesium in the body include the maintenance of healthy blood pressure[34], control of blood glucose[35,36]. Magnesium deficiency can cause a wide variety of features including hypocalcaemia, hypokalaemia and cardiac and neurological manifestations. A chronic low magnesium state has been associated with several chronic diseases including diabetes, hypertension, coronary heart disease and osteoporosis.

Iron (Fe): Iron is an essential metal element for life, though it is one of the most abundant metals on earth; however, it is not readily available for use[37]. Dietary iron is necessary for the production of new red blood cells. It is a component of haemoglobin, which transports oxygen from the lungs to other tissues in the body and it's also found in myoglobin, which is necessary for the storage and diffusion of oxygen in muscle cells. Iron is important in the synthesis of many important cellular components such as Adenine Triphosphate (ATP), transport of oxygen, Deoxyribonucleic Acid (DNA) and electron transport[38]. Anaemia has been associated with the deficiency of iron[39]. Moreover, Zhang *et al.*[40] associated the increasing level of malnutrition with the diminishing level of iron in our foods.

Selenium (Se): Selenium is a component of over 25 different proteins called selenoproteins. Selenoproteins are important in a wide array of physiological processes. Moreover, it is important in the synthesis of glutathione, critical detoxification and free radical neutralizing enzyme[41]. Dietary selenium has been recognized as an antioxidant and the deficiency of this element has been associated with numerous chronic degenerative diseases, including multiple types of cancer, cardiomyopathy and endemic osteoarthropathy[42]. Its optimal intake could potentially prevent various types of cancer and diseases like diabetes, age-related immunosuppression and even problems related to fertility[43].

Manganese (Mn): Manganese is an essential nutrient in many ways. Its key role is in the activation of enzymes that are needed for the digestion and utilization of foods and nutrients. It also plays a role in reproduction and bone growth. It is sometimes called the 'brain' mineral as it is important to mental function[44]. Manganese deficiency is very rare and hard to determine. However, many people may not be getting the optimal levels needed for health. The most common cause of low manganese is a poor dietary intake, either due to a diet lacking in manganese food sources or because of intestinal tract disorders that hinder the absorption of nutrients from food. Table 1 and 2 contain some macro and micro-mineral elements, sources and functions.

Mineral element enrichment of mushrooms: The enrichment of mushrooms with mineral elements can be achieved by growing the mushroom with substrate already spiced with the mineral element of interest. In the case of enrichment with Iron (Fe), the mushroom will be exposed to iron at different concentrations. The cultivation involves cutting and transferring one agar disc (8.0 mm) of an actively growing mushroom to the centre of an already prepared pure culture medium (PDA, Merck, Darmstadt, Germany) containing

Table 1: Some macro mineral elements, sources and function(s)

Minerals	Functions	Sources	References
Sodium	Sodium is the principal cation in extracellular fluids. It regulates plasma volume, blood volume and blood pressure. It is also involved in the acid-base balance of the body, maintenance of osmotic pressure of the body fluids and membrane potentials. It also preserves normal irritability of muscles and cell permeability. It actively participates in the transmission of nerve impulses and the absorptive processes of monosaccharides, amino acids, pyrimidines and bile salts	Table salt, soy sauce, large amounts in processed foods, small amounts in milk, bread, vegetables and unprocessed meats	Soetan *et al.*[45] and Harper *et al.*[46]
Chloride	Chloride is the principal anion in extracellular fluid and participates in acid production in the stomach. It is involved in the regulation of extracellular osmotic pressure and makes up over 60% of the anions in this fluid compartment and is thus important in the acid-base balance and electrolyte balance of the body. It is also involved in gastric fluid and chloride shift in HCO_3-transport in erythrocytes. Chlorine is a component in the hydrochloric acid formation and activation of amylase, a starch digesting enzyme	Table salt, soy sauce, large amounts in processed foods, small, amounts in milk meats, bread and vegetables	Soetan *et al.*[45] and Tejada-Jimenez *et al.*[47]
Potassium	Potassium is the principal cation in intracellular fluid and functions in acid-base balance, regulation of osmotic pressure, conduction of nerve impulse, muscle contraction particularly the cardiac muscle, cell membrane function and Na+ /K+ -ATPase. Potassium is also required during glycogenesis. It also helps in the transfer of phosphate from ATP to pyruvic acid. potassium also functions as a cofactor for several enzymes	Meats, milk, fresh fruits, vegetables, whole grains and legumes	Soetan *et al.*[45] and Yilmaz *et al.*[48]
Calcium	Calcium functions as a constituent of bones and teeth and regulation of nerve and muscle function. In blood coagulation, calcium activates the conversion of prothrombin to thrombin and also takes part in milk coagulation. Blood pressure regulation, immune system health and also as a messenger in cell signalling, membrane permeability Calcium activates a large number of enzymes such as Adenosine Triphosphatase (ATPase), succinic dehydrogenase, lipase etc. It is also required for membrane permeability, the normal transmission of nerve impulses and neuromuscular excitability	Milk and milk products (Yogurt, cheese), seafood, canned fish with bones (salmon, sardines), fortified tofu and fortified soy milk, greens (broccoli, mustard greens, Spinach) and legumes	Soetan *et al.*[45] and Yilmaz *et al.*[48]
Phosphorus	Phosphorus is located in every cell of the body and is vitally concerned with many metabolic processes, including those involving buffers in body fluids. It functions as a constituent of bones and teeth. It is also used in cell membranes and is part of the energy molecules, Adenosine Triphosphate (ATP) and Adenosine Diphosphate (ADP) phosphorylated metabolic intermediates and nucleic acids. It serves to buffer action, (phosphate buffers) and is involved in the synthesis of phospholipids and phosphoproteins. Phosphorus forms a part of the bones in the form of the mineral hydroxyapatite and functions with Ca in bone formation. It is also essential for cell growth, energy utilization, maintaining acid:base balance is required by rumen microbes for optimal growth and activity	Meat, fish, poultry, eggs, milk, processed foods (including soda pop), pumpkin seeds, oysters, beef, sesame seeds and whole wheat bread	Soetan *et al.*[45] and Harper *et al.*[46]
Sulfur	Sulfur is an important component of two amino acids, cysteine and methionine, that are used in most proteins of the body. It is also found in 2 B-vitamins (biotin,and thiamin). Also functions in maintaining bone, cartilage, tendon and blood vessel integrity (contained in chondroitin). Intestinal microbes are capable of synthesizing all of the sulfur containing compounds from inorganic sulfur, however, its high levels in the diet antagonize the use of copper and molybdenum	Meats, poultry, Fish, eggs, milk, legumes and nuts	Arinola[49]

Table 2: Some micro mineral elements sources and function(s)

Minerals	Function	Sources	References
Iodine	Iodine is a basic component of the thyroid hormones, thyroxine and mono-, di- and tri-iodothyronine and it is stored in the thyroid as thyroglobulin and is required for normal thyroid function necessary for syntheses of thyroid hormone, which regulates energy metabolism. Iodine is important for the development of the fetus and the maintenance of the general basal metabolic rate	Seafood, foods are grown in iodine-rich soil, iodized salt, bread and dairy products	Harper *et al.*[46]
Fluoride	It plays a role in the prevention and treatment of dental caries. Fluoride in saliva reduces cavities by reducing acid produced by bacteria and by increasing enamel remineralization after acid exposure. It has a great affinity for calcium and so it is associated with the calcification of bones and teeth	Drinking water fish, fruit juices and teas	Harper *et al.*[46]
Chromium	Works closely with insulin to regulate blood sugar (glucose) levels. It could play a role in maintaining the configuration of the RNA molecule because Cr is particularly effective as a cross-linking agent for collagen	Unrefined foods, liver, brewer's yeast, whole grains, nuts and cheeses	Tuormaa[50]
Molybdenum	Molybdenum is a component of several metalloenzymes including xanthine oxidase, aldehyde oxidase, nitrate reductase and hydrogenase. Xanthine oxidase and aldehyde oxidase play a role in iron utilization as well as in cellular metabolism in electron transport. Xanthine oxidase is actively involved in the uptake and release of iron from ferritin in the intestinal mucosa and in the release of iron from ferritin in the liver, placenta and erythropoietic tissues to the ferrous form. In plants, it plays a role in nitrogen fixation and nitrate assimilation through nitrate reductase which is a key enzyme in the metabolic process in leguminous plants	Legumes, bread and grains, leafy greens, leafy, green vegetables, milk and liver	Harper *et al.*[46] and Tejada-Jimenez *et al.*[47]
Cobalt	Cobalt is present in the body as a part of vitamin B12, which is involved in the manufacture of blood cells, cell growth, reproduction and nervous system function. It is needed for thymine synthesis which is required for DNA synthesis		Guerin *et al.*[51]
Silicon	Silicon is one of the most abundant elements in plant and animal tissue, collagenous connective tissues and bones. It appears to function as a biological cross-linking agent contributing to the structure and resiliency of connective tissue. It plays a role in the calcification of bone and glycosaminoglycan metabolism in cartilage and connective tissue		Harper *et al.*[46]
Nickel	Nickel plays a role in the maintenance of membrane structure, control of prolactin, nucleic acid metabolism or as a cofactor in enzymes		Tejada-Jimenez *et al.*[47]

0, 50.0 or 100.0 mg L^{-1} of iron in form of $FeSO_4 \cdot 7\ H_2O$ at pH 5.5. This will be followed by the incubation of the plates at 25°C for 7 days. The growth of the mushroom formed after 7 days will be assessed by measuring the colony's diameter in two directions that are perpendicular to each other[52]. The biomass (dry mass) will be determined by emptying the entire contents of the Petri dish (mycelium + culture media) into a bottle with distilled water and heating in a water bath (5-10 min) to dissolve the culture medium. Then, the solution will be filtered and the mycelium will be dried in an oven at 60°C until a constant weight will be reached[53,54].

The substrate can be injected with the mineral element of interest[55]. Briefly, for selenium, the substrates (corn cobs) will be sundried and broken into smaller pieces using mortar and pestle. It will be further pulverized into a fine powder using a mill machine. The substrate (corn cobs) will be moistened with water to a concentration of 60%. One thousand grams (1000 g) of the substrate will be packed into polypropylene bags and sealed with paper with the aid of polyvinyl rings. The bags will then be autoclaved for 2 hrs at 121°C. The substrates will be allowed to cool down and then inoculated with 30 g of mushroom spawn. Sodium selenite (50 mg kg^{-1}) will be injected into the substrate. A control with no sodium selenite will also be prepared to serve as a control. The bags will then be kept in the spawn room at 75% relative humidity until the formation of primordial. The bags will then be uncapped and transferred to the fruiting room to allow the normal development of the fruitbodies. The total Se content can then be determined using an inductively coupled plasma mass spectrometry (Agilent ICP-MS 7900, Agilent Technologies, Santa Clara, CA, USA).

Some experimental results: One of the strategies adopted to combat dietary or mineral inadequacies is food bio-fortification with minerals. Bio-fortification of foods with mineral elements is feasible, relatively cheap, efficient and safer than other diet supplementation approaches in preventing nutritional deficiencies[56]. Bio-enrichment of foods is a conspicuous tactic to solve the occurrence of ailments associated with nutrient deficiencies. Supplementation of the mineral into cultivated *Pleurotus* spp., can be embraced to treat symptoms of macro- and micro-element deficiencies. Mushrooms have great potential for uptake and accumulate various elements in their fruiting bodies. Mushrooms are bio-fortified with certain elements; lithium[57], iron[58], selenium[55] and zinc[59] have the potential of being used as nutritional therapy. Based on the functions of Zinc, Selenium and iron, they are indispensable elements that need to be integrated into food crops to enhance the health of the end consumers.

Oyetayo *et al*.[60], the total phenol in *Pleurotus* spp not grown on substrate fortified with iron and zinc were 10.7 mg GAE/g of the extract while the *Pleurotus* spp fortified with Fe, Zn and Zn+Fe had 13.3, 15.8 and 16.7 mg GAE/g of extract, respectively. An increase was also observed in the flavonoids content of *Pleurotus* spp fortified with Fe, Zn and Zn+Fe with flavonoid values of 7.0, 8.2 and 8.4 mg QE/g of extract compared with the unfortified *Pleurotus* spp., with flavonoid content of 5.8 mg QE/g. Gąsecka *et al*.[61] obtained higher phenolic compounds in fortified mushrooms, *P. ostreatus* and *P. eryngii* concurrently enriched with Se and Zn with the value of 13.38 mg g^{-1} of extract and 10.86 mg g^{-1} of extract, which was higher than control. Medicinal mushrooms synthesize a great number of phenolic compounds like polyphenols, hydroxybenzoic acids, flavonoids, tannins, hydroxycinnamic acids, stilbenes, 4-hydroxybenzoic, ferulic, p-coumaric, protocatechuic, t-cinnamic, vanillic acids, cinnamic acid and lignans with other secondary metabolites; like lectins, lactones, terpenoids, alkaloids[61,62]. Flavonoids are very important bioactive constituents with a variety of biological potentials like a free radical scavengers, metal chelators and various physiological activities.

Extracts from mushrooms fortified with Zn have the highest scavenging activity (96.3%) against DPPH. However, the OH^- scavenging activity of extract from mushrooms fortified with Zn (96.3%) and the control, BHT (97.1%) were not significantly different. Extract from non-fortified mushroom, mushroom fortified with Zn and BHT has a similar scavenging activity of 95.0, 96.8 and 97.1% against NO radical.

Extracts from mushrooms bio-enriched with Se and Se+Zn displayed significant antioxidant activities by improving Reactive Oxygen Species (ROS) and inhibiting lipid peroxidation[63]. Supplementation of mushroom growth substrate with selenite and Zn sulfate significantly increased DPPH scavenging activity in fruiting bodies. Bio-fortified mushrooms have greater antioxidative properties and could enhance oxidative stress in humans. Bhatia *et al.*[64] had earlier reported that extracts of the Se-enriched *P. sajor-caju* and *Volvariella volacea* mushroom spp., exhibited higher reducing and scavenging activities than the non-enriched *P. sajor-caju*. Moreover, the study conducted by Poniedzialek *et al.*[63] reported that biofortification of *P. ostreatus* and *P. eryngii* with selenium significantly improved their antioxidant and reducing activities, indicating the potential applicability of such bio-fortified ingredients as a functional food. In another study on the nutraceutical property of *Pleurotus* enriched with selenium, it was observed that selenium-enriched *Pleurotus* spp., showed significant antioxidant and antimicrobial properties[55,65].

Safety assessment: There is a need for a safety assessment of mineral element enriched mushrooms. This will help to determine if the permissible level(s) of these mineral elements have not been exceeded. The safety and nutritional effect of the mushroom fortified with mineral elements still need to go animal bioassay. This may involve the evaluation of the enriched mushrooms in rats fed dietary inclusions of the mineral element fortified mushroom. Relevant haematological, nutritional and safety parameters such as liver function tests could be monitored in the fed rats to determine their level of safety.

Future perspective: The importance of mineral nutrients in the maintenance of life cannot be overemphasized. Though, the required daily intake of these mineral elements is small compared particularly with nutrients such as carbohydrates and lipids, they are, however, indispensable components that must be present in a healthy diet. The absence of some of these mineral elements in our food had often been associated with one deficiency disease or the other. It is therefore expedient that these mineral elements are adequately supplied through our food. One way of doing this is through enrichment of our foods with these elements.

CONCLUSION

Mushrooms can absorb mineral elements and can bio-accumulate them as functional organic compounds during growth. Mushrooms can therefore be used as a vehicle to supply minerals that are not in adequate amounts in our diet. Some of these essential elements that can be bio-accumulated by mushrooms are selenium, iron, zinc, copper and so on. In one of our studies, *Pleurotus* spp., enriched with selenium showed significant antioxidant and antimicrobial properties. Therefore, selenium-enriched *Pleurotus* spp., could serve as a rich source of natural antioxidants and antimicrobial food for the enhancement of the body against oxidative damage and pathogenic invasion. Fortification of *Pleurotus* spp., with essential metals should therefore be encouraged as this can improve its application as health-promoting foods.

SIGNIFICANCE STATEMENT

The present review revealed the potential of mushrooms as a vehicle that can be used to introduce essential elements into our body through the consumption of mushrooms fortified with essential mineral elements. Mineral element enrichment of mushrooms is therefore a definite strategy to solve the problem of mineral element deficiency which is common as a result of eating foods that lack these essential nutrients. Furthermore, the consumption of mineral-enriched mushrooms possesses a double advantage of supplying useful mycochemicals and essential minerals that can help in promoting stable physiological homeostasis in man.

REFERENCES

1. Oyetayo, O.V., 2011. Medicinal uses of mushrooms in Nigeria: Towards full and sustainable exploitation. Afr. J. Traditional Complementary Altern. Med., 8: 267-274.

2. Cencic, A. and W. Chingwaru, 2010. The role of functional foods, nutraceuticals and food supplements in intestinal health. Nutrients, 2: 611-625.
3. Aluko, R.E., 2012. Functional Foods and Nutraceuticals. 1st Edn., Springer, New York, ISBN: 978-1-4614-3480-1, Pages: 155.
4. Alongi, M. and M. Anese, 2021. Re-thinking functional food development through a holistic approach. J. Funct. Foods, Vol. 81. 10.1016/j.jff.2021.104466.
5. Roberfroid, M.B., 2000. Prebiotics and probiotics: Are they functional foods? Am. J. Clin. Nutr., 71: 1682S-1687S.
6. Hasler, C.M., 2002. Functional foods: Benefits, concerns and challenges: A position paper from the American council on science and health. J. Nutr., 132: 3772-3781.
7. John, R. and A. Singla. 2021. Functional foods: Components, health benefits, challenges, and major projects. DRC Sustainable Future, 2: 61-72.
8. Shi, J., F. Shahidi and C.T. Ho, 2005. Asian Functional Foods. 1st Edn., CRC Press, Boca Raton, ISBN: 9780429113864, Pages: 672.
9. Mallavadhani, U.V., A.V.S. Sudharkar, K.V.S. Satyanarayana, A. Mahapatra, W. Li and R.B. van Breemen, 2006. Chemical and analytical screening of some edible mushrooms. Food Chem., 95: 58-64.
10. Ma, G., W. Yang, L. Zhao, F. Pei, D. Fang and Q. Hu, 2018. A critical review on the health promoting effects of mushrooms nutraceuticals. Food Sci. Hum. Wellness, 7: 125-133.
11. Ogidi, C.O., V.O. Oyetayo and B.J. Akinyele, 2020. Wild Medicinal Mushrooms: Potential Applications in Phytomedicine and Functional Foods. In: An Introduction to Mushroom. Passari, A.K. and S. Sánchez (Eds.), IntechOpen, London, United Kingdom, ISBN: 978-1-78985-955-3, pp: 118-126.
12. Barros, L., R.C. Calhelha, J.A. Vaz, I.C.F.R. Ferreira, P. Baptista and L.M. Estevinho, 2007. Antimicrobial activity and bioactive compounds of Portuguese wild edible mushrooms methanolic extracts. Eur. Food Res. Technol., 225: 151-156.
13. Oyetayo, F.L., A.A. Akindahunsi and V.O. Oyetayo, 2007. Chemical profile and amino acids composition of edible mushrooms *Pleurotus sajor-caju*. Nutr. Health, 18: 383-389.
14. Oyetayo, V.O., A. Nieto-Camacho, B.E. Rodriguez and M. Jimenez, 2012. Assessment of anti-inflammatory, lipid peroxidation and acute toxicity of extracts obtained from wild higher basidiomycetes mushrooms collected from Akure (Southwest Nigeria). Int. J. Med. Mushrooms, 14: 575-580.
15. Oyetayo, V.O. and E.T. Akingbesote, 2022. Assessment of the antistaphylococcal properties and bioactive compounds of raw and fermented *Trametes polyzona* (Pers.) justo extracts. Microb. Biosyst., 7: 1-7.
16. Oyetayo, O.V., A. Nieto-Camacho, T.M. Ramırez-Apana, R.E. Baldomero and M. Jimenez, 2013. Total phenol, antioxidant and cytotoxic properties of wild macrofungi collected from Akure Southwest Nigeria. Jordan J. Biol. Sci., 6: 105-110.
17. Prashanth, L., K.K. Kattapagari, R.T. Chitturi, V.R.R. Baddam and L.K. Prasad, 2015. A review on role of essential trace elements in health and disease. J. NTR Univ. Health Sci., 4: 75-85.
18. Bhattacharya, P.T., S.R. Misra and M. Hussain, 2016. Nutritional aspects of essential trace elements in oral health and disease: An extensive review. Scientifica, Vol. 2016. 10.1155/2016/5464373.
19. White, P.J. and M.R. Broadley, 2005. Biofortifying crops with essential mineral elements. Trends Plant Sci., 10: 586-593.
20. Bonham, M., J.M. O'Connor, B.M. Hannigan and J.J. Strain, 2002. The immune system as a physiological indicator of marginal copper status? Br. J. Nutr., 87: 393-403.
21. Uriu-Adams, J.Y. and C.L. Keen, 2005. Copper, oxidative stress, and human health. Mol. Aspects Med., 26: 268-298.
22. Harris, E.D., 2001. Copper homeostasis: The role of cellular transporters. Nutr. Rev., 59: 281-285.
23. Bost, M., S. Houdart, M. Oberli, E. Kalonji, J.F. Huneau and I. Margaritis, 2016. Dietary copper and human health: Current evidence and unresolved issues. J. Trace Elem. Med. Biol., 35: 107-115.

24. Ginocchio, R., P.H. Rodríguez, R. Badilla-Ohlbaum, H.E. Allen and G.E. Lagos, 2002. Effect of soil copper content and pH on copper uptake of selected vegetables grown under controlled conditions. Environ. Toxicol. Chem., 21: 1736-1744.
25. Chaignon, V., I. Sanchez-Neira, P. Herrmann, B. Jaillard and P. Hinsinger, 2003. Copper bioavailability and extractability as related to chemical properties of contaminated soils from a vine-growing area. Environ. Pollut., 123: 229-238.
26. Sadhra, S.S., A.D. Wheatley and H.J. Cross, 2007. Dietary exposure to copper in the European Union and its assessment for EU regulatory risk assessment. Sci. Total Environ., 374: 223-234.
27. Shetty, S.R., S. Babu, S. Kumari, P. Shetty, S. Hegde and A. Karikal, 2013. Role of serum trace elements in oral precancer and oral cancer-A biochemical study. J. Cancer Res. Treat., 1: 1-3.
28. Hambidge, M., 2000. Human zinc deficiency. J. Nutr., 130: 1344S-1349S.
29. Brown, K.H., S.E. Wuehler and J.M. Peerson, 2001. The importance of zinc in human nutrition and estimation of the global prevalence of zinc deficiency. Food Nutr. Bull., 22: 113-125.
30. Rink, L. and P. Gabriel, 2000. Zinc and the immune system. Proc. Nutr. Soc., 59: 541-552.
31. Kaur, K., R. Gupta, S.A. Saraf and S.K. Saraf, 2014. Zinc: The metal of life. Compr. Rev. Food Sci. Food Saf., 13: 358-376.
32. Wang, L.C. and S. Busbey, 2005. Acquired acrodermatitis enteropathica. N. Engl. J. Med., Vol. 352. 10.1056/NEJMicm030844.
33. Ross, A.C., B.H. Caballero, R.J. Cousins, K.L. Tucker and T.R. Ziegler, 2012. Modern Nutrition in Health and Disease. 11th Edn., Wolters Kluwer Health Adis, London, United Kingdom, ISBN: 9781605474618, Pages: 1616.
34. Sales, C.H., L.F.C. Pedrosa, J.G. Lima, T.M.A.M. Lemos and C. Colli, 2011. Influence of magnesium status and magnesium intake on the blood glucose control in patients with type 2 diabetes. Clin. Nutr., 30: 359-364.
35. Larsson, S.C. and A. Wolk, 2007. Magnesium intake and risk of type 2 diabetes: A meta-analysis. J. Internal Med., 262: 208-214.
36. Rodríguez-Morán, M., L.E. Simental Mendía, G.Z. Galván and F. Guerrero-Romero, 2011. The role of magnesium in type 2 diabetes: A brief based-clinical review. Magnesium Res., 24: 156-162.
37. Philpott, C.C., 2006. Iron uptake in fungi: A system for every source. Biochim. Biophys. Acta (BBA)-Mol. Cell Res., 1763: 636-645.
38. Puig, S., L. Ramos-Alonso, A.M. Romero and M.T. Martínez-Pastor, 2017. The elemental role of iron in DNA synthesis and repair. Metallomics, 9: 1483-1500.
39. Kassebaum, N.J., R. Jasrasaria, M. Naghavi, S.K. Wulf and N. Johns *et al*., 2014. A systematic analysis of global anemia burden from 1990 to 2010. Blood, 123: 615-624.
40. Zhang, X.G., Y.N. Peng, X.R. Li, G.D. Ma and X.Q. Chen, 2015. Screening of iron-enriched fungus from natural environment and evaluation of organically bound iron bioavailability in rats. Food Sci. Technol. Campinas, 35: 58-65.
41. Brown, K.M. and J.R. Arthur, 2001. Selenium, selenoproteins and human health: A review. Public Health Nutr., 4: 593-599.
42. Fernandes, A., L. Barros, A. Martins, P. Herbert and I.C.F.R. Ferreira, 2015. Nutritional characterisation of *Pleurotus ostreatus* (Jacq. ex Fr.) P. Kumm. Produced using paper scraps as substrate. Food Chem., 169: 396-400.
43. Milovanović, I., M. Stajić, J. Ćilerdžić, T. Stanojković, A. Knežević and J. Vukojević, 2014. Antioxidant, antifungal and anticancer activities of se-enriched *Pleurotus* spp. mycelium extracts. Arch. Biol. Sci., 66: 1379-1388.
44. Horning, K.J., S.W. Caito, K.G. Tipps, A.B. Bowman and M. Aschner, 2015. Manganese is essential for neuronal health. Annu. Rev. Nutr., 35: 71-108.
45. Soetan, K.O., C.O. Olaiya and O.E. Oyewole, 2010. The importance of mineral elements for humans, domestic animals and plants: A review. Afr. J. Food Sci., 4: 200-222.

46. Harper, H.A., R.K. Murray, D.K. Granner and P.A. Mayes, 1999. Harper's Biochemistry. 25th Edn., McGraw-Hill, New York, USA., ISBN-13: 9780838536841, Pages: 927.
47. Tejada-Jiménez, M., A. Galván, E. Fernández and Á. Llamas, 2009. Homeostasis of the micronutrients Ni, Mo and Cl with specific biochemical functions. Curr. Opin. Plant Biol., 12: 358-363.
48. Yilmaz, A.B., M.K. Sangun, D. Yaglıoglua and C. Turan, 2010. Metals (major, essential to non-essential) composition of the different tissues of three demersal fish species from Iskenderun Bay, Turkey. Food Chem., 123: 410-415.
49. Arinola, O.G., 2008. Essential trace elements and metal binding proteins in Nigerian consumers of alcoholic beverages. Pak. J. Nutr., 7: 763-765.
50. Tuormaa, T.E., 2000. Chromium, selenium and copper and other trace minerals in health and reproduction. J. Orthomolecular Med., 15: 145-157.
51. Guerin, T., R. Chekri, C. Vastel, V. Sirot, J.L. Volatier, J.C. Leblanc and L. Noel, 2011. Determination of 20 trace elements in fish and other seafood from the French market. Food Chem., 127: 934-942.
52. Kim, Y.K., C.L. Xiao and J.D. Rogers, 2005. Influence of culture media and environmental factors on mycelial growth and pycnidial production of *Sphaeropsis pyriputrescens*. Mycologia, 97: 25-32.
53. Ogidi, O.C., M.D. Nunes, V.O. Oyetayo, B.J. Akinyele and M.C.M. Kasuya, 2016. Mycelial growth, biomass production and iron uptake by mushrooms of *Pleurotus* species cultivated on *Urochloa decumbens* (Stapf) R. D. Webster. J. Food Res., 5: 13-19.
54. Ogidi, C., M. Nunes, M. de Silva, V. Oyetayo, B. Akinyele and M.C. Megumi, 2017. Growth rate and selenium bioaccumulation in *Pleurotus* species cultivated on signal grass, urochloa decumbens (Stapf) R. D. Webster. Curr. Res. Nutr. Food Sci., 5: 137-143.
55. Fasoranti, O.F., C.O. Ogidi and V.O. Oyetayo, 2019. Nutrient contents and antioxidant properties of *Pleurotus* spp. cultivated on substrate fortified with selenium. Curr. Res. Environ. Appl. Mycol., 9: 66-76.
56. Bouis, H.E. and A. Saltzman, 2017. Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. Global Food Secur., 12: 49-58.
57. Dwyer, J.T., K.L. Wiemer, O. Dary, C.L. Keen and J.C. King *et al*., 2015. Fortification and health: Challenges and opportunities. Adv. Nutr., 6: 124-131.
58. Mleczek, M., M. Siwulski, P. Rzymski, S. Budzyńska, M. Gąsecka, P. Kalač and P. Niedzielski, 2017. Cultivation of mushrooms for production of food biofortified with lithium. Eur. Food Res. Technol., 243: 1097-1104.
59. Zięba, P., K. Kała, A. Włodarczyk, A. Szewczyk, E. Kunicki, A. Sękara and B. Muszyńska, 2020. Selenium and zinc biofortification of *Pleurotus eryngii* mycelium and fruiting bodies as a tool for controlling their biological activity. Molecules, Vol. 25. 10.3390/molecules25040889.
60. Oyetayo, V.O., C.O. Ogidi, S.O. Bayode and F.F. Enikanselu, 2021. Evaluation of biological efficiency, nutrient contents and antioxidant activity of *Pleurotus pulmonarius* enriched with zinc and iron. Indian Phytopathol., 74: 901-910.
61. Gąsecka, M., M. Mleczek, M. Siwulski and P. Niedzielski, 2016. Phenolic composition and antioxidant properties of *Pleurotus ostreatus* and *Pleurotus eryngii* enriched with selenium and zinc. Eur. Food Res. Technol., 242: 723-732.
62. Chaturvedi, V.K., S. Agarwal, K.K. Gupta, P.W. Ramteke and M.P. Singh, 2018. Medicinal mushroom: Boon for therapeutic applications. 3 Biotech, Vol. 8. 10.1007/s13205-018-1358-0.
63. Poniedziałek, B., M. Mleczek, P. Niedzielski, M. Siwulski and M. Gąsecka *et al*., 2017. Bio-enriched *Pleurotus* mushrooms for deficiency control and improved antioxidative protection of human platelets? Eur. Food Res. Technol., 243: 2187-2198.
64. Bhatia, P., C. Bansal, R. Prakash and T.P. Nagaraja, 2014. Selenium uptake and associated anti-oxidant properties in *Pleurotus fossulatus* cultivated on wheat straw from seleniferous fields. Acta Aliment., 43: 280-287.
65. Fasoranti, O.F., C.O. Ogidi and V.O. Oyetayo, 2018. Phytochemical constituents and antimicrobial evaluation of ethanolic extracts from *Pleurotus* spp. cultivated on substrate fortified with selenium. Microb. Biosyst. J., 3: 29-39.