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Mushroom Biotechnology in Nigeria–implications for Food Security, Environment and Public Health, A Review

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Authors' contributions

This work was carried out in collaboration between all authors. Author UKA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors VAE, OEO and SA managed the analysis of the study and literature searches . All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Mushroom biotechnology is one of the three aspects of mushroom science which has to do with mushroom products and involves the application of the principles of fermentation technology, mushroom biology/microbiology and bioprocess. It is the application of modern biotechnology in mushroom production whose products increase resistance to disease in humans and also balances nutrients in diet and enhancing of the immune system. Determination of genetic diversity and similarity using genetic molecular tools such as Deoxyribonucleic acid (DNA) finger printing, random amplified polymorphic DNA(RAPD) markers, deoxyribonucleic acid(DNA) sequence analysis, the determination of mating type patterns and improved strain selection, solid state and submerged fermentations are all biotechnologically – driven. Worldwide, there is a constantly growing popularity of mushrooms and the tremendously increased use for mushroom products in commercially significant amounts, this makes it very essential to apply biotechnological techniques in the large scale production of mushrooms. This will result in a detailed, reliable and accurate identification and classsification of mushroom species which is a valuable tool in the cultivation of mushrooms for higher yields and improve on consumer preferred qualities such as shape, size, texture, shelf-life, nutrient content and resistance to adverse environments, pests and diseases.

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This review therefore seeks to highlight the major biotechnological techniques employed in the production of mushroom products such as nutraceuticals and current fermentation principles and its effect on sustained access to adequate food and nutrition and a cleaner ecosystem and better health.

Keywords: Mushroom biotechnology; deoxyribonucleic acid; ecosystem; fermentation; nutraceuticals.

1. INTRODUCTION

Mushrooms are macrofungi with a distinctive fruiting body which can be either epigeous or hypogeous and large enough to be seen with the naked eyes and to be picked by hand [1] Mushroom is a fleshy, spore bearing fruiting body, a fungus, typically produced above ground on soil or on its food source. It is a special type of edible fungi forming flesh umbrella like fruiting bodies. They belong to the class Bacidiomycetes and order Agaricales. They do not possess chlorophyll, like green plants for manufacturing their food [2]. The mushroom on earth has been estimated to be about 140,000 yet only 14,000 (10%) are known [3]. With it’s favourable climatic conditions of tropical rain forest in the south and sub-saharan climate in the north, Nigeria has diverse species of mushrooms. Ethnomycology of edible and medicinal mushrooms is reported among the Igbos [4], Yoruba [5], Igala [6], Bini [7] and Hausa [8]. In other countries of the world ethnomycology of edible and medicinal mushrooms is well documented. They include among others, Zambia [9], Ghana [10], Benin [11], Guatemala [12], Nepal [1314] and India [15].

Mushroom biotechnology is concerned with mushroom products and encompasses the principles of fermentation technology, mushroom biology/microbiology and bioprocess. Mushroom products have a generalized or tonic effect, which in some cases may actprophylactically by increasing resistance to disease in humans from the balancing of nutrients inthe diet and the enhancing of the immune systems. To make mushrom production worthwhile, for example, in a pharmaceutical industry, quality control of functional health preparations and nutritional supplements, requires correct identification of medicinal mushrooms [16] and the most reliable method is not by phenotipic observation but by the use of molecular genetic tools. This is so because Deoxyribonucleic (DNA) which features in this method is the component containing the blue print that specifies the biological development and composition of every form of life. DNA sequencing of mushrooms is the process of determining the exact order of the nucleotide bases in them. Generating a DNA sequence for a mushroom is to determine the patterns and make up genetic traits, diversity and growth forms. Highly conserved genes provide information on the general properties of their known relatives. Analysis of the rDNA sequence has the advantage that it not only enables species identification but also permits phylogenic analysis [17]. The aim of this review paper is therefore to highlight the biotechnological techniques employed in the production of mushroom products and the implication to food security, environment and public health.

2. Application of Biotechnological Tools in Identification

For accurate quality control of mushroom products especially those for functional health preparations, drugs and nutraceuticals for pharmaceutical companies, the need to carry out proper identification can not be overemphasized. Identification of mushrooms for a long time had been on examination with the naked eyes based on phenotypic characteristics. Prior to the use of biotechnology in identification of mushrooms many have died by eating poisonous species. Poisonous mushrooms have claimed the lives of historical figures. in history. Such casualties include Pope Clement VII, King Charles VI of France and Czar Alexis of Russia [8]. The most celebrated casualty was that of Roman Emperor Claudius Ceasar, there was however the belief that the mushrooms that killed him were deliberately poisoned before it was introduced into his meal by political enemies [8]. There are still cases of mushroom poisoning where proper identification using biotechnology is not done.

Identification based on phenotypic characters had been reported to be impossible to distinguish between genetically related species [16]. The determination of genetic identity is also important to make suitable biological analysis about population, structure and evolutionary ways within and among species [18]. By using genetic molecular tools, genetic diversity and similarity has been established by various authors. For example, eighteen speciality mushroom accessions using DNA finger printing and ribosomal rRNA gene sequencing have being characterized [19]. Diversity in Pleurotus eryngii using RAPD and its sequence analysis has been determined and that grouping based on physiological parameters is closely related to RAPD based grouping is also established [20]. Genetic diversity among 37 Pleurotus species of mushroom has also been determined using randomly amplified polymorphic DNA technique [21]. In a similar study, morphological and RAPD markers established genetic diversity among different pleurotus species. Information on genetic make-up of the diverse mushroom species in Nigeria is sparse and localized, and includes DNA sequence analysis of Voucher extracted genomic DNA of sixteen mushrooms found in Lagos, Nigeria and comparison with that in the GenBank Library Database in Washington, USA, for purposes of identification [17]. The use of molecular genetic tools in identification by a few authors have added to the knowledge of genetic characteristics of indigenous mushrooms. For example, mushroom species such as *Chlorophyllum molybdates*, *Lentinus squarrosulus, Daedalea elegans, Pleurotus Ostreatus, Agaricus bisporus* have been studied using Random Amplified DNA-Polymerase Chain Reaction (RAPD–PCR) and the potential for co–breeding among the species has been established [22]. The molecular characterization of Termitomyces species using rDNA internal transcribed sequence (ITS) has also been carried out. Understanding the genetic make-up of indigenous mushroom species would also facilitate gene isolation and recombinanation to improve consumer preferred qualities like uniform size, shape, colour, texture and nutrient content. Year round availability of preferrred species, resistance to adverse environment pests and diseases, especially for commercial scale production [22]. The employment of biotechnology in identification is a very critical tool in the cultivation of mushrooms since it is more accurate and reliable in distinguishing between edible and poisonous species. It also helps to establish antimicrobial and pharmacological propeties of the mushrooms.

3. CURRENT BIOTECHNOLOGY TOOLS IN MUSHROOM CULTIVATION IN NIGERIA

The cultivation of gourmet and medicinal mushrooms is becoming increasingly popular. The annual world production of cultivated mushrooms is on the increase. The history of mushroom cultivation dates back to the late 19th century in America; and to the early 1960s in India, with twenty-fold production increase in four decades [23]. The mushroom industry in Nigeria is described as infantile, compared to some other countries [24] due to paucity of information to develop the industry [25]. Factors responsible for the infantile status of mushroom industry in Nigeria have been reported to include poor state of infrastructure, scarcity of mushroom scientists, poor knowledge of diversity of indigenous species and dearth of mushroom taxonomists [26]. A study on socio-economic and cultural factors that affect mushroom production in the South West Nigeria reported to have the highest number of edible and medicinal mushrooms compared to the two other major tribes in the country [24], revealed that only 8% of the few known mushroom growers in the region had annual mushroom production of over 1500 kg; 56% of them cultivated imported varieties; 96% had been in the mushroom industry for not more than 10 years; while only 20% of the farmers sold their products outside their immediate vicinity, with average gross profit margin of N116,114.00 ($921.54) per farmer [27]. In Nigeria, *Auricularia auricular Judae* (Bull.*) Quél, Lentinus squarrosulus Mont., Pleurotus tuber regium* (Fr.*) Singer and Volvariella volvacea (*Bull.*)* Singer are some of the common edible mushrooms with nutritional properties that have been successfully cultivated on small-scale basis [8]. Table 1 shows some indigenous mushrooms with nutritional properties. The advantages of cultivating mushrooms includes encouragement of mycophagy and all-round availability of mushrooms. Biotechnology processes such as bioconversion of the mushrooms during cultivation results in a clean ecosystem. A large quantity of agricultural wastes is used up, a high production per surface can be obtained and even after picking the new fruit bodies the spent substance can still be used as a good conditioner.

Table 1. Some nutritional indigenous mushrooms

Mushrooms names	References
Termitomyces mammiformis	[25]
*Auricularia auricular*Judae (Bull.)	[8]
Lentinus squarrosulus mont	[28]
Calvatia cyathiformis (Bose.) Morg.	[8]
Lactarius triviralis	[25]
Lentinus tigrinus	[25]
Lentinus subnudus Berk	[23]
Lactarius trivialis Fr.	[8]
Pleurotus tuberregium (Fr.)Singer.	[29]
Psathyrella atroumbonata Pegler	[8]
Termitomyces microcarpus (Berk and Br.) Heim	[8]
Termitomyces robust (Beeli) Heim	[8]
Tricholoma lobayense Heim	[8]
Volvariella volvacea (Bull)	[5].

Mushroom production is one of the few large-scale application of microbial technology. Mushrooms lack chlorophyll, so they depend on other organisms for food, absorbing nutrients from the organic materials in which they live. The living body of the fungus is mycellium made out of a tiny web of threads or (filaments) called hyphae. Sexually compatible hyphae fuse and start to form spores under specific conditions. When a spore settles in a suitable environment, it can germinate and branch to form mycellium, which is capable of forming fruiting bodies. However, in the cultivation of edible mushrooms no use is made of spores. The desired mushroom must be able to colonise the substrate before other fungi or bacteria do so. Therefore the mycelium must be pure and must be inoculated on a sterile substrate to obtain a spawn. The growth of mushrooms involves the vegetative stage in which the mycelia grows profusely and the reproductive (fruiting) stage. Lignocellosic materials are the main substrates for mushroom production. Mushrooms grow on almost all cellulosic agricultural waste material. Mushrooms lack seeds, therefore without the application of biotechnology some species of mushrooms cannot be cultivated easily. Mushrooms can be cultivated without genetic modification for year round production and consumption. Mushroom yields vary according to biological and environmental conditions, as well as pests and diseases present during cultivation. Many different techniques and substrates have been successfully utilized for mushroom cultivation. For production of mushroom fruiting bodies, various forms of Solid state fermentation (SSF) are employed, whereas for mycelial biomass and BAM production, submerged fermentation is preferable to produce a more uniform biomass and pharmaceutical products. Solid State Fermentation in the production of mushroom fruit bodies that has been sucessfully applied in Brazil [30].

4. SOLID- STATE FERMENTATION (SSF)

Solid-state fermentation (SSF) is defined as any fermentation process occurring in the absence or near absence of free liquid, employing an inert substrate (synthetic materials) or a natural substrate (organic materials) as a solid support [31,32]. SSF is most appropriate for bioconversion of plant raw materials into value-added products, such as mushroom fruiting bodies, fodder, secondary metabolites and enzymes. In SSF, with small energy consumption, the nutrient medium is concentrated and high volumetric productivity can be achieved in a smaller bioreactor. In SSF a concentrated product can be obtained from a cheap substrate such as agro-industrial residue. In SSF, natural lignocellulosic materials especially food–industry residues is used for cultivation since such residues are rich in sugars and other useful compounds. However, the use of lignocellulosic substrates might make the product purification process more difficult. For this reason, this cultivation technique would be most appropriate for the colonization of growth substrate by mushroom mycelium, when the whole fermented substrate can be used.

5. SOLID STATE FERMENTATION OF MUSHROOMS IN NIGERIA

5.1 *Pleurotus tuber-regium* (Fr) Sing

Agricultural wastes such as cassava peelings, corn straw, oil palm fruit fiber, rice straw and wild grass have been sucessfully utilized; Plantain/banana leaves, Farms, roasted plantain retailers. Domestic wastes such as waste paper. Industrial waste such as saw dust [8,27].

5.2 *Psathyrella atroumbonata* Pegler

Agricultural wastes such as corn cobs, banana leaves, corn stems, corn husks, guinea corn shaft, guinea grass, rice straw, sawdust of mahogany wood and oil palm fruit fibres [31]. Rice straw have also been used for the successful cultivation of this mushroom. Banana leaves have also been used [31].

5.3 *Volvarealla volvocea*

Agricultural wastes such as paddy straw, oil palm fibre, sawdust and a mixture of sawdust and oil palm fibre have been used successfully in the SSF of this mushroom [33].

5.4 *Pleurotus ostreatus jacq*

Agricultural wastes such as Rice straw and rice husks [34]; Cocoa pods [29].

5.5 *Pleurotus pulmonaris* (Fr) Quel

Agricultural waste such as Oil palm fruit fibre Oil palm mills *Pleurotus pulmonarius* (Fr.) Quél, [31] Cassava peelings [33].

5.6 *Lentinus subnudus* (Berk)

Industrial waste such as Coconut fruit fibre Farms [8].

5.7 *Lentinus squarrosulus* (Mont)

Agricultural waste such as wheat straw and bran wheat [35]. Industrial waste such as sawdust [8].

6. SUBMERGED FERMENTATION OF MUSHROOMS IN NIGERIA

One of the current biotechnological procedures used in the production of mushroom mycelia is submerged fermentation which can be used for synthesis of pharmaceutical substances with anticancer, antivirus and immuno-stimulatory effects from the nutritive mushroom biomass. Various cultivation techniques and strategies have been used for submerged cultivation of medicinal mushrooms, depending on the fungi physiological and morphological peculiarities and their behavior under different environmental conditions. The advantage of fermenter use is that it is easier to control environmental conditions as temperature, agitation, dissolved oxygen and medium pH. Five fermentation techniques used in the cultivation of this mushroom includes batch fermentation which is the simplest. The second technique is the Fed–batch fermentation which is a strategy that involves adding one or more of the nutrients during fermentation, because the high concentrations required for high final growth and product yields might inhibit growth if added in total at the start of the fermentation [30,36]. The third technique is the bistage control of pH which was proposed based on the fact that pH of 3.0 improved growth and a constant pH of 6.0 increased exopolysaccharide production [37]. Another fermentation technique is the Two-Stage culture process which was proposed based on the fact that ganoderic acid production was favored at a low oxygen tension. There is also the immobilized culture technique which involves the introduction of polyurethane foam sheet into the medium of a submerged fermentation in an Erlenmeyer flask [37]. However, there is very scarce information on BAM production by immobilized mushrooms. Finally, there is the three-stage light irradiation strategy in submerged fermentation. Submerged fermentation of many mushrooms have been successfully carried out by various authors, they include *Cordyceps militaris* [38], *Collybia maculata* [39]; *Grifola fondosa* [40]. In Nigeria, using submerged fermentation exopolysaccharides have been detected in *Lentinus squarrosulus* [28]; exopolysaccharides have been detected in *Termitomyces clypeatus* [41].

7. ADDITION OF PLANT OILS, SURFACTANTS AND mORGANIC ACIDS IN SUBMERGED FERMENTATION OF MUSHROOMS

To increase the production of Biologically Active Metabolites (BAM) by medicinal mushrooms, many investigators have used some stimulating agents, including fatty acids, surfactants, vegetable oils and organic solvents. These agents are known to mediate cell permeabilization by disorganizing the cell membrane and/or directly affecting the level of enzyme synthesis involved in product formation, thereby contributing to enhanced production of target products [40,39,42,30,37]. Plant oil plays a role and a function of antifoam agent in fermentation that has been reported to be favorable for the mycelial growth in several medicinal mushrooms and fungi, and to increase the production of bioactive metabolites [38,37]. Several plant oils, which can be used as antifoam agents, may also be beneficial to mushroom growth and BAM production. Soy, peanut, safflower, corn, sunflower and olive oils stimulate growth and increase biomass density and promotes excretion of fungal extracellular polysaccharides in liquid medium [37]. Such stimulation is due to a partial incorporation of lipids in the cell membrane, thereby facilitating the uptake of nutrients from the medium. Plant oils like castor oil, soybean oil and peppermint have been used as additives in submerged fermentation of *Trametes spp* resulting in mycelial growth and stimulation of cell growth [37]. The stimulation of cell growth by oil in this study was caused by the partial incorporation of lipids in the cell membrane, thereby facilitating the uptake ofnutrients from the medium. Another explanation is that oils directly affect the level of enzyme synthesis involved in ploysaccharide formation [38]. Organic solvents can also be used as additives and act as a relatively effective method for cell permeabilization; they are less expensive than other stimulating agents and may be eliminated by simple evaporation. For example, toluene, chlorofoam, acetone and heptane have been used sucessfully [39]. In Nigeria, there is litle or no information on the use of additives in submerged fermentation of mushrooms.

8. TECHNIQUES OF PRODUCT RECOVERY

In submerged fermentation biomass is generally recovered by filtration under suction or centrifugation. When it is intended to quantify the biomass of a sample,it is generally filtered through a pre-weighed filter paper (GF/C Whatman) or a membrane with a standardized pore size [37]. Some authors filter thebiomass, wash it off the filter with distilled water, recoverit from the washings by centrifugation and then dry it until constant weight at temperatures ranging from 50 to 105°C. No studies have been done about the effect of drying temperature on charring of the biomass or the loss of volatile cell components other than water.The recovery of the biomass obtained by SSF is adifficult task because the mycelium binds tightly to the solid particles of the substrate. Therefore, it is normally impossible to determine the dry weight directly by the gravimetric method.

9. IMPLICATIONS FOR FOOD SECURITY

A nation is said to have food security if it is able to provide its people with sustained access to sufficient and quality food needed for active and healthy living. For quite a long time,mushrooms have been part of some people's diet and cultures in Nigeria [43,44]. The nutritional properties of mushrooms has been reported by many authors [8,23,25,28].

Some spp of mushrooms are highly nutritious Table (1), it contains all classes of food. Most mushrooms have a high protein content, usually about 20–30% by dry weight. They are a good source of proteins for vegetarians. They also contain fibers which helps to lower cholesterol and is also good for the digestive system.They contain niacin and other important Vitamins which serve as another good supplement for vegetarians. Mushrooms contain vitamin D for the absorption of calcium. They contain copper which aids the body absorb oxygen and create red blood cells. Mushrooms contain more selenium than any other form of produce. Potassium, an important mineral which regulates blood pressure and keeps cells functioning properly is also found in mushrooms. Phosphorus, zinc, magnesium have also been found in mushrooms. It contains all the essential amino acids and essential minerals, It has low fat and is therefore good for dieters [45,46]. Mushrooms are used to supplement and complement the nutritionally deficient cereals and are known as the highest producers of protein per unit time and area [19]. The average protein content (dry weight) of Nigerian mushrooms double that of vegetables such as asparagus and potatoes and is about 4 to 12 times higher than that of fruits such as tomatoes, carrots and oranges [47,35,45]. They are internationally acclaimed as poor man's meat because they are good substitute for meat which peasants cannot afford [48]. The local people hunt for them and make money from such collections [34]. Mushroom cultivation serves as the most efficient and economicallly viable biotechnology for the conversion of lignocellulus waste materials into high quality protein food resulting in improved quality and quantity of food

[49]. Efforts in the application of mushroom biotechnology to improve quality and quantity of food includes a preliminary study on the mating and strain selection in tropical culinary–medicinal mushroom *Lentinus squar rosulus* mont. Other contributions includes determination of the genetic characteristics of three edible indigenous mushrooms: *Chlorophyllum molydites*, *Lentinus squarrosulus* and *Daedelea elegans* and two commercially important species *Pleurotus ostreatus* and *Agaricus bisporus*using Random Amplified DNA-Polymerase Chain Reaction (RAPD-PCR) and Un-weighted Pair Group Method [22]. Studies have also been carried out on the extention of shelf-life to make the mushroom available all the year round. Mushroom biotechnology is therefore a strategy to bring about better nutrition and food security by generating a relatively cheap source of high quality food protein, provision of cheap source of health enhancing dietary supplements in form of nutriceuticals.

10. MUSHROOM NUTRACEUTICALS

The term nutraceuticals was originally created by a man named Dr Stephen L. De Felice and is derived by combining the words "nutrition and "pharmaceutical'' [5]. The Merriam–Webster dictionary defines nutraceuticals as "a food stuff (as a fortified food or a dietary supplement) that provides health benefits". They are foods or food products with some sort of health benefit, including the prevention and treatment of disease. A nutraceutical is demonstrated to have a physiological benefit or provide protection against chronic diseases. Dietary supplements can be found in many forms such as Tablets, capsules, soft–gels, gel–caps, liquids or powders. The ingredients in these products can include: vitamins, minerals, herbs or other botanicals, amino acids and substances such as enzymes, organ tissues, glandular tissues and metabolites. Nutraceuticals are fast becoming a common addition to our everyday diets. It is now established that components of food may play an integral role in the link between food and health. The products are also referred to as functional foods, signifying they and their components may provide a health benefit beyond basic nutrition [50]. Medicinal mushrooms have been used as a dietary supplement or medicinal foods which improves biological function, resulting in good health and fitness. They are also used in the prevention and treatment of human diseases. Mushrooms are the ultimate health food [51]. For example, *Auricularia auricula-judae, Cordyceps sinensis, Ganoderma lucidum, Grifola frondosa* and *Pleurotus ostreatus* reduce the total cholesterol level; *Tramella fuciformis* reduce the bad cholesterol level; *Cordeceps sinensis, Grifolafrondosa* and *Lentinua edodes* reduce the triceride level; *Auricularia auricula–judae* and *Ganoderma lucidum* reduce the platelet binding; *Ganoderma lucidum* and *Grifola frondosa* reduce arterial pressure; while *Agaricus bisporus* and *Grifolafondosa* reduce glycemia [52]. There is intense industrial interest currently in a novel class of compounds extractible from the mycelium or fruiting body of mushrooms. These compounds are called "mushroom nutraceuticals" [51]. The use of standardised extracts of the mycelium or fruiting bodies of the mushrooms is what distinguishes nutraceuticals from both the use of whole mushrooms (as food) and of single chemicals (as a drug). Whole mushrooms, like all other natural materials, vary considerably in their quality and their beneficial action may be unreliable. Single chemicals often provide such intense responses that they are accompanied by very unpleasant side effects.

11. IMPLICATIONS FOR THE ENVIRONMENT

Worldwide, pollution of air, soil and water by toxic chemicals as a result of industrialization and use of pesticides in agriculture has become an environmental concern. Mushrooms have the great potential of transforming a wide variety of hazardous chemicals. Mushrooms are decomposers, secreting strong extra-cellular enzymes due to their aggressive growth and biomass production [24,26]. As a result of their high toxicity some chemicls have been noted as recalcitrant environmental contaminants by the United Nations Environmental Agency (USEPA). Some species of mushrooms have the ability to transform recalcitrant pollutants like polycyclic aromatic hydrocarbons (PAH'S).

Mycoremediation of oil polluted soils have been reported by various authors [53]. In Nigeria, several tonnes of agricultural, industrial and municipal wastes that overwhelms the nations waste disposal machinery and are potentially degraded by mushrooms. The cultivation of mushrooms using agricultural, industrial as well as domestic waste has gone a long way in solving the nation's waste disposal problem which has resulted in a cleaner ecosystem.

The use of refuse and lignocellulosic waste materials in cultivation goes a long way to solve the waste disposal and management problem which has become a global challenge. This stategy of cleaning the ecosystem is environmentally friendly. Mushrooms which have been used in bioremediation of oil polluted soils includes *Lentinus subnudus* [54] and Pleurotus tuber-regium [5].

12. IMPLICATIONS FOR PUBLIC HEALTH

Antibiotic resistance to existing antibiotics has become a global concern. This has led to a constant search for new substances that can improve biological functions and make people fitter and healthier. In the past three to four decades, research findings have pointed to mushrooms as important source of pharmacologically important bioactive compounds that can improve health. They have been found to contain the most potent natural medicines. “Let food be thy medicine” is good advice indeed and with mushrooms that is especially true, as they contain some of the most powerful natural medicines on the planet.

Mushrooms are known to make a balanced diet which is said to control and modulate many functions of human body and consequently participates in the maintenance of state of good health, necessary to reduce the risk of many diseases. They contain complex carbohydrates that stimulates the immune system. Mushrooms contain a great variety of secondary metabolites such as phenolic compounds, triterpenes which are steroid–like molecules that inhibit histamine release and have anti-inflammatory properties, steroids, polyketides and phenols [43].

The antimicrobial, antioxidant and anticancer, antiallergic, anticholesterol and antitumor properties of organic, hot and cold water extracts of Nigerian mushrooms have been reported [55, 56,57,58,59,]. This is not surprising since antibiotics have been successfully isolated from mushrooms as shown in (Table 2). They have also been used in the treatment of malnutrition in chidren, diabetes, obesity or hyperlipidemea, sterility, anaemia mumps, fever and protein defieciency [7]. Mushrooms have been shown to promote digestibility in ruminant animals [60]. In a similar study, Ganoderma lucidum, was reported to successfully reduce pain in cancer patients and when orally administered it enhances natural killer (NK) cells and cytogenic lymphocytes activity. In yet another study, *Ganoderma lucidum* was shown to have hypoglycemic, anti-hyperglycemic, anti-inflammatory and liver protective effects on rats [61,49,62,63]. *Pleurotus tuberregium*, a common species in the southern part of Nigeria has been reported to be useful in some combinations to cure headache, stomach ailments, colds and fever [63] asthma, smallpox and high blood pressure [63] while *Lentinustuber-regium* and *Lentinus tigrinus* are used for treating dysentery and blood cleansing respectively. *Auricularia* species have been traditionally used for treating hemorrhoids and various stomach ailments [50].

13. COLLECTIONS AND IDENTIFICATIONS OF NIGERIAN MUSHROOMS

The mushrooms were collected in Sheda Science and Technology Complex, Sheda it’s environs and were identified in March, 2012 at the Plant Science and Biotechnology Department, University of Benin, Benin City. Coloured Mushroom Field Guide Book [64] and Internet Facility (google.com) were also used for mushroom identification (See Plates 1 and 2).

Table 2. Isolated antibiotics from selected mushrooms

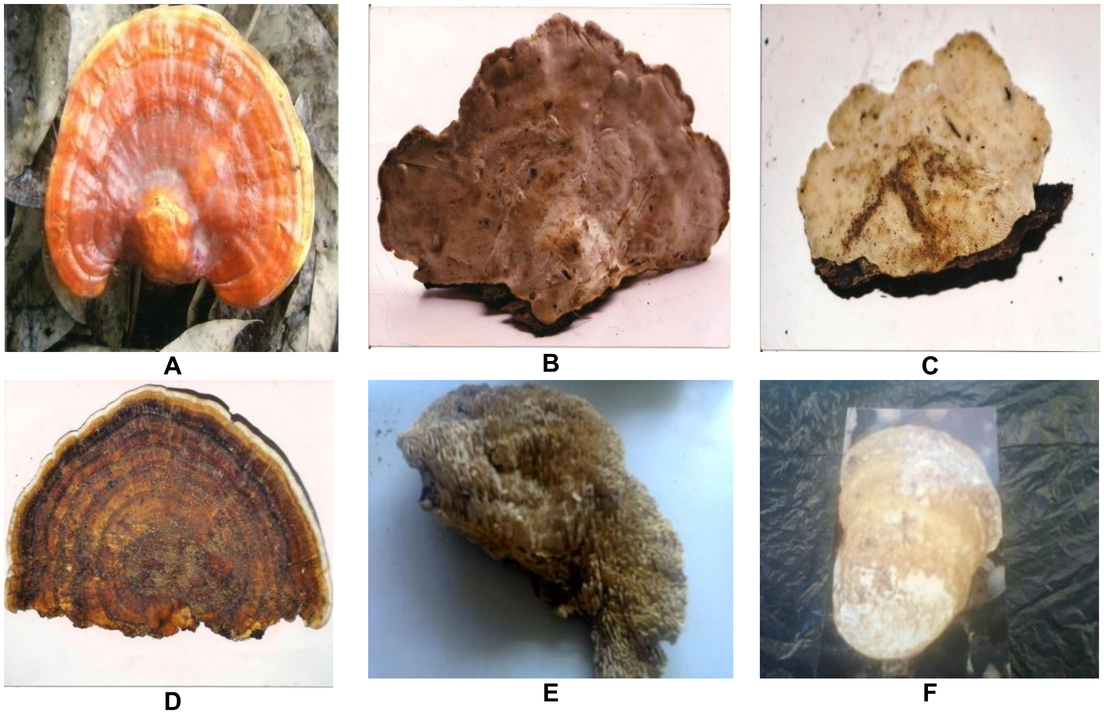
Mushrooms	Antibiotics
Armillaria mellea	Armillaric acid
Fometopsis officinalis	Agaricin
Agaricus campestris	Campestrin
Calvatia gigantia	Calvacin
Coprinus species	Coprinol
Trametes versicolor	Corolin
Lentinus edodes	Cortinellin
Ganoderma lucidum	Ganomycin
Sparassis crispa Sparassol	Schizophyllan.
Schizophyllum commune	

(Source, [60])

14. CONCLUSION

It is pertinent to conclude that the use of biotechnological tools in mushroom production canonly lead to high yield, better quality products and in the long run sustained access to sufficient food. It will also ensure health of the people and a clean ecosystem.

Plate 1. Edible mushrooms known and utilized in nigeria
{A} Pleurotus florida, {B} Pleurotus ostreatus, {C}Agaricus bisporus, {D}Auricular auricularia, {E}Boletus edulis, {F}Boletus sp, {G}Macrolepiota procera, {H}Panus flavus, {I}Lentinus squarrosulus, {J}Lepisda flacida, {K}Chlorophyllum molybdates, {L}Lacterius deliciosus
Pictures taken: BY Asemota, U.K(2012)



Plates 2. Medicinal mushrooms known and used in nigeria
{A} Ganoderma lucidum, {B}Ganoderma applanatum, {C}Polypore sp 1, {D}Trametes versicolor, {E} Polypore sp 2, {F} Fomes fomentarius
Pictures taken: BY Asemota, U.K(2012)

15. RECOMMENDATIONS

This review paper shows that mushrooms are metabolically versatile fungi that could be used in various biotechnological applications. However, the application of biotechnology in the production of mushrooms in Nigeria is still very green. The majority of the applications outlined above need further research and development. Open forums in form of workshops, talk shows, radio and television which should serve as an awareness drive for the rural people should be organized. Pure cultures (spawn) of mushrooms which have been properly identified using genetic molecular tools should be made easily available to mushroom farmers especially the local ones to reduce the incidence of poisoning and also increase mycophagy. Researchers are also encouraged to collaraborate with the international community of mushroom growers, researchers and other stakeholders.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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