Current Developments in Mushroom Biotechnology in Sub-Saharan Africa

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Abstract

Africa constitutes at least 25% of the total mushroom biodiversity in the world, but barely contributes up to 0.4% of total mushroom sales and new mushroom products on the global market. The economic importance of mushrooms in Sub-Saharan Africa (SSA) is increasingly gaining attention on the continent, but there is a paucity of information on the commercial production of edible mushrooms and current research into the cultivation of local mushroom species in SSA. Between 1990 and 2013, commercial production of edible mushrooms improved slightly and amounted to approximately 5000 tons per annum but with an economic value of less than 5 million dollars. Less than 500 people were engaged in mushroom production units per year per country in SSA. Zimbabwe, Swaziland, Namibia, South Africa, Malawi, Benin Republic and Ghana are the leading mushroom producing countries in Sub-Saharan Africa. In Southern, Eastern, Western and Central African countries, per capita consumption of both wild and cultivated mushrooms is very low and, generally, less than 25% of Africans do not have mushrooms as part of their staple diet compared with four decades ago. A cross-sectional survey of indigenous people from across communities in Uganda, Ghana, Cameroon, Ethiopia and Nigeria strongly indicated that, due to modernization, local mushroom diets and recipes have been lost over time. In Cameroon, a traditional soup called "Achu soup" used to be mushroom based but now 80% of Cameroonians serve the dish with meat or smoked fish. Efforts to develop modern based African mushroom meals have yet to be effective. Despite remarkable developments in the last decade in the field of mushroom biotechnology, which have been widely exploited in Europe, America, China and now Latin America, research on the mega-biodiversity of mushrooms in SSA, and the recovery and conservation of indigenous edible mushroom germplasm, has not been extensively undertaken by African research institutions and universities. Continuous growth of the mushroom industries of Latin America, China, Europe and America has, and will continue to, set stiffer challenges on the global market for African mushroom growers. For Africa to fully benefit from the tremendous potential of mushroom entrepreneurship, future research and development directed at enhanced cultivation of local species, improved spawn production, exploitation of local substrates, adequate seed banks, new culinary product development and preservation as well as marketing strategies built on the right institutional support are critical components. Some insights into these measures are outlined in this paper.

Key words: *Sub-Saharan Africa, Mushroom Biotechnology, Ganoderma, Pleurotus tuberregium, Termitomyces, Commercial production, Culture collections, Current development*.

Introduction

For the full benefit of mushrooms to be realized in Africa, a thorough understanding of African mushroom resources, and strategies for the cultivation, marketing and development of endogenous species, will need to be aggressively pursued. Africa constitutes at least 25% of the total mushroom biodiversity worldwide but contributes barely 0.4% of total mushroom sales and new mushroom products on the global market. Yet mushrooms are well known in most indigenous African recipes (Mpeketula, 2008) and, at the onset of the rainy seasons, it is customary to find rural people across many African countries (for example, Cameroon, Nigeria, Malawi, Ghana, Benin Republic, Togo, Uganda, Ethiopia, Kenya, Equatorial Guinea and Zimbabwe) going out to search mushrooms from decaying wood and palm trees (Yongabi *et al*., 2004).

The cultivation of mushrooms for food and medicine is increasingly popular across the world, including Africa. However, the pace of progress in Africa is slow. Never before in contemporary times has the potential of mushrooms been so widely known and advocated. Twenty years ago, Chang (1993) described mushrooms as the gourmet food of the 21st Century. Hitherto, their application has transcended food and medicine into bioremediation of oil spills. Commendable progress on mushroom cultivation techniques has been widely reported (Chang, 1993) but many prospective farmers in SSA who want to grow mushrooms do not have access to information. Some mushroom farmers are aware of cultivation techniques using a range of substrates but, generally, they face a lack of information on the commercial potential of indigenous mushrooms. Mushroom production capacity of SSA is, proportionally, minimal compared to that of Latin America, China and Europe (Martinez-Carrera, 2002; Sanchez *et al*., 2002). Chioza and Ohga (2014) reported 240 kg per grower in Malawi, with a sale price of about two USD per kg. These values are not significantly different across SSA. The mushroom sector in Africa is characterized by a lack of infrastructure, inadequate technical support, a scarcity of mushroom scientists and poor knowledge of mushroom diversity (Okhuoya *et al*., 2010). About 95% of all articles published in Africa and elsewhere on the state of mushroom production in Africa point strongly to the under exploitation of mushrooms.

Current Developments

Mushroom cultivation and spawn development in SSA

There is an endemic lack of basic epistemic knowledge about a “one magic bullet substrate” for raising mushrooms with minimal contamination. Additionally, the lack of operating capital, technical assistance, strain and/or spawn availability, and marketing strategies are grossly inadequate to rapidly improve the mushroom sector. So far, African mushroom growers have only succeeded in growing *Pleurotus* species (Oyster mushrooms) especially *Pleurotus ostreatus, Pleurotus sajo-caju* and *Pleurotus pulmonarius,* on corn cobs, rice husks, maize bran and sawdust. Cultivation of these exotic mushrooms is, generally, expensive for an average

African farmer. In the coming decades, efforts in Africa would have to be concentrated on developing spawn from local mushroom species as well as utilizing local available tropical weeds and grasses usually left unused or burnt *in situ* on many farms. At the Phyto-biotechnology Research Foundation Ecological Farm in Bamenda, Cameroon (www.phytobiotechcameroon.org), spawn development and fruiting of *P. ostreatus* using local grasses such as elephant grass stems (*Pennisetum purpureum*) and spear grass (*Heteropogon contortus*) has achieved 70% biological efficiency levels. Laboratory experiments suggest that initial crude fiber from these grasses were 80% utilized when the first flush of *P. ostreatus* fruit bodies were harvested.

Generally, mushroom growers across Africa use rice bran, rice husks, maize husks and bran (as well as sawdust) in various proprietary proportions, together with calcium oxide for pH stabilization. Although yields have been commendable, thorough scientific analyses of these substrates and biological efficiency studies are lacking. The Phytobiotechnology Research Foundation (PRF) runs a mushroom cultivation unit with intensive research on the domestication and commercial cultivation of local mushroom species **(www.phytobiotechcameroon.org).** PRF is a Non-Governmental Organization registered with the Cameroon Government CIG Reg. No: NW/GP/29/07/10856 and 0068/E.29/1111/Vol.8/APPB, with a Euroaid No: 958820266. The word Phytobiotechnology was first framed by Dr Kenneth Yongabi Anchang who is currently the director. The Foundation's work on mushrooms is not only focused on the cultivation of mushrooms for food but also for medicine. Innovative work has steadily progressed on the preparation of widely cultivated *P. ostreatus* spawn using a number of local substrates prepared from farm wastes in Cameroon, using novel energy saving substrate sterilization methods involving a plant-derived biocide.

Reasonable progress has also been made on the fiber utilization potential of *P. ostreatus* mycelia. Crude fiber analysis of some agricultural wastes in Cameroon has been carried out. These included corncobs, sawdust, corn stalks and cowpea shells. A study on fiber utilization by oyster mushroom mycelia demonstrated excellent conversion of fiber and lignocellulose. In this study, we noted that sawdust from some trees in Cameroon has the highest amount of fiber (56.33%), and a decrease of 40.72% fiber was noted after mycelia colonization. Crude fiber in sorghum (the lowest amount) was reduced from 3.21% to 1.39% after mycelial colonization. This study showed conclusively that the mycelia of *P. ostreatus,* has high fiber degradation capacity. We noted in our study that the higher the crude protein content of the substrate, the higher its utilization by the *P. ostreatus* mycelium. In a separate study, in which no energy was used to pasteurize substrates, salt extracts of *Aspilia africana* leaves were introduced into the substrates. These treatments reduced microbial contamination of the substrates by 95%, thus reducing the burden of intensive pasteurization using biomass fuel. More than 85% of the population of SSA encounter energy shortages and largely depend on fuel wood. Our studies have conclusively demonstrated the tripartite advantages of *P. ostreatus* mycelium as excellent converter of fiber for food, waste utilization and the production of digestible feed for animals, as well as providing clues about low cost substrate sterilization technology.

It was noted that fungal mycelium alone without mushroom fruiting could be used to treat agricultural wastes while concomitantly producing digestible livestock feed. This is very crucial since, in most African countries, the population is predominantly agrarian and produces huge quantities of waste during the farming season. Many of these waste materials, especially rice husks and some tropical grasses, take a long time to break down, and when used in livestock feed formulae unconverted, are rejected by the animals. These laboratory studies are very necessary tools to establish suitable local conditions for sustained mushroom cultivation and applications in SSA.

Plate 1: A mushroom grower in Bamenda, Cameroon, growing *Pleurotus ostreatus* on a mix of rice husk, maize bran and sawdust using plastic bags.

Plate 2: Fresh *Pleurotus ostreatus* fruit bodies

In Namibia, Malawi and Zimbabwe, the Zero Emission Research Initiative (ZERI, www.zeri.org) program has demonstrated success with the cultivation of *P. ostreatus* on a wide range of substrates including water hyacinth (www.unam.na/centres/zeri/malawi.htm).

The need to explore and document standard mushroom cultivation protocols on local African substrates is critical to sustaining mushroom production in SSA. The ZERI Program in the last decade embarked on extensive capacity building across Africa, particularly in the University of Namibia where one of the ZERI mushroom research projects is housed. Other related progress has been made in Ethiopia, Malawi, Uganda, Nigeria and many other countries across Africa. In Nigeria, for instance, Dr Kenneth Yongabi Anchang and Prof Michael Agho of blessed memory spearheaded the ZERI mushroom research effort from 2000 to 2005 supported by the ZERI Foundation and Abubakar Tafawa Balewa University, Bauchi, Nigeria. The findings of Yongabi and Agho suggested that less than 15% of Africans grow mushrooms. The major challenge remaining unresolved is the poor knowledge of mushroom spawn production technology which requires financial commitments and capital requirements. We noted that this has excluded so many small-scale farmers. We also noted the need to strengthen capacity for dealing with microbial contamination of substrates, and control strategies for pest infestation on mushroom farms which require the use of synthetic agrochemicals.

Costs remain generally high for many local farmers. Energy is required for pasteurization with more than 70% of the farmers using biomass fuels, thus posing a serious challenge. Research findings from the PRF and the Catholic University of Cameroon, which has built simple and indigenous biotechnologies hinged on local resources for more sustained mushroom production in Africa, provide solutions to the problems highlighted by Yongabi and Agho in 2005 in Nigeria.

Current status of spawn development from African indigenous mushroom species

The major barrier to mushroom cultivation and production in Africa is the dependence on imported exotic mushroom spawn. This has necessitated the adoption of greenhouses and special conditions foreign to the farmers and adding to their costs. The need to develop spawn from indigenous local mushroom species is a critical step in boosting mushroom production in Africa. So far, this has not been achieved. At the moment, spawn and spawn banks have been developed from less than 5% of African indigenous mushrooms strains. This is another critical component for the survival of the mushroom industry in Africa. For instance, *Agaricus* species grow wild on decaying palms in Africa but no spawn banks of these species exist. Yet, in Latin America, Europe and Asia, *Agaricus* species are widely cultivated on a huge industrial scale. With rapid urbanization, climate change, and ecological degradation that are already palpable in SSA, the palm tree population is rapidly dwindling by approximately 5% per annum. The potential impact of this is the loss of *Agaricus* strains. Similarly, *Pleurotus tuberregium* is another tremendous mushroom resource predominant in West and Central Africa that has remained largely under-utilized.

Local efforts towards the domestication of local mushroom species. *Pleurotus tuber-regium* mycelia/spawn developed from sporophore tissue at the PRF Research Centre, Cameroon (Pic: Kenneth Yongabi *with Pleurotus tuberregium* fruit, 2012).

Classification/taxonomy of indigenous African mushroom species requires elaborate studies and expertise and, at present, there are only a few mushroom mycologists in SSA able to take up this challenge. Our field studies across the Guinean savanna area of Nigeria (Bauchi, Gombe and Jigawa States), northern Cameroon, as well as the grassland fields of the northwest region of Cameroon, suggest that there is some indigenous knowledge base that might be useful in the classification of some local mushroom species. This indigenous knowledge could be used by African mushroom mycologists for taxonomic purposes. Such knowledge, if carefully exploited, could be incorporated into modern day fungal taxonomy for the 21st century, and could be a useful guide to molecular taxonomic tools. This is an interesting area and anticipates further research work.

In addition to investigating the proximate, nutritional and medicinal profiles of extracts of local mushrooms, the PRF Centre is also engaged in co-opting indigenous knowledge resources to identify and classify local mushroom species in Cameroon. In this context, *Pleurotus tuber-regium,* an edible mushroom containing 29.2% protein collected in the southwest region of Cameroon, and *Termitomyces tetani*, another edible mushroom containing 21% protein from Baligham in the Santa sub-division of Cameroon, have been analyzed. A rich folklore exists among the local people of Baligham in the North West (NW) Region of Cameroon, who can identify *Termitomyces* species from the termite's mound. Local names in the dialects of the people of Tikari in NW Cameroon are used to describe mushrooms that exist symbiotically with insects. Our studies at the PRF Centre further demonstrated that acetone and methanolic extracts of some collected mushroom samples such as *Auricularia auricula* and *T. titanicus* inhibited the growth of *Staphylococcus aureus*, a common clinical isolate that is rapidly becoming resistant to antibiotics. Although aqueous extracts showed no activity, further studies are planned with other mushrooms. Data from phytochemical studies are shown in Tables 1 and 2.

Table 1. Phytochemical content of wild mushrooms from NW Cameroon

Edible mushroom type	**Alkaloids**	**Tannins**	**Saponins**	**Glycosides**
Termitomyces tetani Acetone extract Methanol extract	 ND ND	 + ND	 ND ND	 Not determined Not determined
Pleurotus teberregium Acetone extract Methanol extract	 ND ND	 ND ND	 ND +	 + (c-glycosides present) - (c-glycosides absent)

Table 2. Crude protein analysis and preliminary bioassay

Edible mushroom type	**Crude Protein**	***Staphylococcus aureus***
Termitomyces tetanicus Acetone extract Methanol extract	21.0%	Inhibition zone greater than 6 mm diameter
Auricularia auricula Acetone extract Methanol extract	42.2%	Inhibition zone greater than 6 mm diameter

Some of these preliminary data have been noted in a number of reports across Africa but more in-depth studies are required to develop these findings, and a need for African mycologists to continuously document and conserve the ethnomycology of Africa. In this context, a rare *Ganoderma* species has been identified growing in the wild in the Boyo Division of the North West Province of Cameroon.

A rare species of *Ganoderma* (Alem in Kom dialect) growing on local decaying trees in grassland fields of the northwest region of Cameroon (Pic. Kenneth Yongabi, 2012)

Plate 2: *Ganoderma* sp. identified as predominant in most areas of Northern Nigeria, Cameroon and many parts of the world

Comments on the application of tropical mushroom biotechnology in healthcare

Natural products from tropical mushrooms with bioactive properties are increasingly being prospected across the African mycosphere, and effort that is imperative for improved healthcare of Africans (Yongabi *et al*., 2004). There is a rich source of traditional knowledge on the use of mushrooms to treat diseases like cancer, diabetes and HIV/AIDS. Increased awareness of its importance encouraged Professor Omon Isikhuemhen and other African mycologists to organize international conferences on the edible and medicinal mushrooms of Africa annually during the past five years with a view to developing pharmaceuticals and nutriceuticals with therapeutic value from African mushrooms. Some of these efforts are currently being translated into healthcare products. For example, in Ghana, Dr. Adoteh Gideon of Accra Polytechnic, in collaboration with Aloha Medicinals, USA, has developed Immune Assist 24/7 from tropical *G. lucidum* and other mushroom species for enhancing the immunity of HIV/AIDS patients.

Immune Assist 24/7 developed by Gideon Adoteh, Accra Polytechnic

A similar initiative in Cameroon spearheaded by Kenneth Yongabi at the PRF Research Centre in Cameroon, has observed that therapeutic foods derived from *G. lucidum* and *Agaricus species* in a proprietary blend called Kaybiotics improves the immunity of HIV/AIDs patients in Cameroon. The PRF Centre has shown that, in Cameroon, many local mushroom species belonging to more than 23 genera exist. Dominant among these are *P. tuber-regium, T. titanicus, T. robusta, Agaricus campestris, Flammulina spp*, as well as many different *Ganoderma* species.

Plate shows a catalogue of mushroom surveys in Northern Nigeria, showing a rich biodiversity among many unidentified local species (Pic: Kenneth Yongabi, 2005)

Plate 4: *Phellinus baumii*, a wild mushroom species from Cameroon with potential antimicrobial activity

Novel potential of tropical mushrooms

During the last decade, research across Africa has demonstrated that mushrooms have a high potential in bioremediation. Mushroom spent substrate is, potentially, useful for the bioremediation of oil contaminated soil and detoxification of noxious elements in soil and water ecosystems. There is a need to strengthen research efforts in this direction. Mushrooms are formidable biocatalysts in the degradation of oil contaminated habitats, regenerating biotic microflora as well as bringing about abiotic balance. African mushroom biotechnologists and mycologists need to progress this further for the sustainable development for the continent. Discussions on mushroom science and development have been predominantly limited to academic circles but stakeholders in Africa must strive to implement research findings for the visible benefit of Africans.

The use of mushrooms to treat wastewater in Africa was first reported by the author (Yongabi, 2004) who demonstrated that *P. tuber-regium* sclerotia serve as mycocoagulants, potentially acting as a polyelectrolyte (Yongabi *et al*, 2010). Mushroom production can boost tourism; mycotourism still remains to be explored on the continent. Mushroom mycelia have the potential to treat diabetic wounds (Yongabi *et al*, 2010), which needs to be further explored.Yongabi in 2010 also showed that mushrooms have a strong potential application in tropical infectiology and healthcare. In the area of animal husbandry, the use of mushrooms as an animal feed supplement has strong potential that is being examined in Ghana and Cameroon.

Horizons of new mushroom biotechnology for SSA

There are increasing new opportunities opening up in the production and commercialization of mushrooms due to globalization. This is also creating new opportunities and challenges for the sector in Sub-Saharan Africa. To increase mushroom production rapidly, possibly to measure up comparatively with the fast-track production of western countries, China and Latin America, a holistic integrated approach will need to be considered. This includes amongst other things, a focus on increased production through the use of modern biotechnology, development of indigenous mushroom species, new spawn production strategies both for new and existing mushroom species, institutional support from African governments, improvements in preservation technology, new product development, and aggressive marketing strategies.

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