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INAUGURAL LECTURE SERIES 310

# HUNGER ON RAMPAGE: FUNGI TO THE RESCUE!

By

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# INTRODUCTION

Providence charted my academic career right from the very beginning to this level; hence, it is with total humility and immense gratitude to the most High God that I stand before this august assembly today to deliver this inaugural lecture, the 310th in the series. I must hasten to add that this is the first to be given by the first female professor from the Department of Crop Production and Protection of this University.

Mr. Vice-Chancellor Sir, an inaugural lecture is an occasion of significance in the career of an academic staff and a core University tradition worldwide. Inaugural lectures provide professors with the opportunity to inform colleagues, the campus community and the general public of their work to date, including current research and future plans. It is recognized as a platform for a professor to address his/her audience in his/her area of specialization by presenting his/her contribution to knowledge or scholarship. In the light of the foregoing, I have decided to make a presentation of my academic stewardship and the compass for my future research agenda. In this inaugural lecture, I have carefully x-rayed my research trajectory till date, spanning about three decades commencing from the Department of Botany and Microbiology at the University of Ibadan, where I first cut my teeth; to my academic sojourn in the Faculty of Agriculture, University of The Gambia where I was a pioneer staff; as well as University of Dar es Salaam, Tanzania where I developed intellectual muscle; United States Department of Agriculture (USDA), Sydney, Montana, USA, where I sharpened my methodological skills; to my current position in the Faculty of Agriculture of this University where I attained professional maturity and became the first female professor and head of Department. Based on the experience garnered over these years across variegated academic climes, I have chosen to speak on the topic which aptly describes the nucleus of my academic voyage- ***"Hunger on rampage: fungi to the rescue!"***

## HUNGER AS A SOCIAL MENACE

The best way to understand a complex issue is to start with the simplest idea associated with it, just as starting with the simplest building blocks in building anything at all.

Hunger is deprivation while its outbreak may make its sufferers go on rampage and sometimes go berserk and wild or angry. Hunger is real and evident everywhere especially here in Nigeria where people pick from dust and wastes or even go to bed on empty stomach. Hunger is also the most extreme manifestation of the multi-dimensional phenomenon of poverty and the eradication of hunger is therefore, instrumental to the eradication of other dimensions and manifestations of poverty (FAO, 2015). Persistent widespread hunger impedes progress of efforts aimed at poverty reduction and it also weakens the foundation for broad-based economic growth. Hunger also represents an extreme instance of market failure, because the people who are most in need of food are the least able to express this need in terms of demand and access (FAO, 2012).

The right to food was first explicitly expressed in the 1940s in the Universal Declaration of Human Rights and the Food & Agricultural Organization (FAO) Constitution (FAO, 2012). However, progress towards its implementation has been little. The United Nations (UN) Committee on Economic, Social Cultural Rights has facilitated the task of implementation of this fundamental right by adopting in 1999, the General Comment on the Right to Food, which specifies how each state can meet their obligations to respect, protect and fulfill this right. Unfortunately, in spite of these comments, too little purposeful action has been taken towards eradicating hunger. The number of hungry people in the world is not falling fast enough to meet the ambitious but pragmatic goal enshrined in the 1996 World Food Summit (WFS) Plan of Action which called for a reduction in the number of undernourished people from 816 million in 1990-92 (the base period) to 408 million by 2015 (which has passed now!). The latest figures from FAO show that to meet the target, the number of hungry will have to fall by more than 22 million every year, compared with the 6 million a year attained on average since the 1990s. This slow progress aided the inability to attain the goal by 2015. The fact that this slight downward trend in the number of hungry has been driven by handful of large countries is also a cause of concern and it is morally reprehensible. Most developing countries have recorded either an increase or no significant change in the number of undernourished people in their midst (FAO, 2012). Poverty rate in Nigeria was 33.1% as at August, 2017 together with high cost of living; cost of accessing health care has also been on the high side even in government hospitals thereby, causing many to result to self-medication. The rate of inflation as at July, 2017 stood at 16.05% affecting people's ability to provide for themselves and their families (National Bureau of Statistics, 2017). These aggravated the growing ethnic conflicts in the country. For a country like Nigeria with massive wealth and huge population to support commerce, this level of poverty is very alarming. These problems are hinged largely on poor management system of resources and inadequate monitoring and evaluation of projects that were aimed at improving living conditions of the citizens. This has resulted to high level of insecurity at all levels in the country. There is therefore, the need for awareness, proper orientation and rescue measures to be put in place.

Much of poverty alleviation efforts seem to be driven by the belief that success in poverty reduction will come from market-driven economic development, and would automatically take care of the problem of hunger. However, this thinking does not take into account three points: first, that poverty reduction takes time, while the hungry needs immediate relief (a hungry man does not have the luxury of time); second, that in contrast to many diseases for which cures are either unknown or unaffordable, the means to feed everyone are readily and cheaply available (so, dealing with hunger is not a question of what to do but how to do it); and third, that hunger is as much a cause as an effect of poverty. Unless hunger is reduced, progress in cutting poverty is bound to be slow. The existence of hunger in a world of plenty is not just a moral outrage; it is also a form of short-sightedness from an economic viewpoint: hungry people make poor workers, they are bad learners (if they go to school at all), with risk of poor cognitive, social, and emotional development of children younger than 3 years in age (Rose-Jacobs *et al.*, 2008; Horton and Steckel, 2013). They are prone to sickness and die young because their immunity is low. Hunger is also transmitted across generations, as underfed mothers give birth to underweight children whose potential for mental and physical activity is impaired; thereby, perpetuating a seemingly intractable cycle of misery, deprivation and backwardness. The productivity of individuals and the growth of entire nations are severely compromised by widespread hunger. Hunger breeds desperation, and the hungry are easy prey to politicians who seek to gain power and influence through crime, force or terror, thereby, endangering national and global stability. It is, therefore, in everyone's self-interest – rich and poor alike – to fight hunger. Otherwise, as it is said, a time will come that those who have eaten cannot afford to sleep because those who have not eaten are on rampage! A former Minister of Finance was quoted in September, 2013 as saying that poverty rate in Nigeria is no longer 70% but 68%! That was then, now that recession is written all over, can this be taken as an improvement that can guarantee peace and safety for the rich (since the poor and the hungry have no such luxury as peace)? A direct attack on hunger will greatly improve the chances of meeting the other Millennium Development Goals, not only for poverty reduction, but also those related to education, child mortality, maternal health and disease (FAO, 2012).

## CRITICAL FACTORS IN NIGERIA'S FOOD SECURITY

Nigerian economy used to be highly regulated until 1986 when there was a transition to deregulation as the dominant economic philosophy with far reaching effects on the economy and the well-being of the people. This affected the food security of the nation negatively because while food supply improved considerably after deregulation especially in the immediate post deregulation period, the ability of the citizens to access this food deteriorated significantly and the food security position became worsened. The right to food and the right to be free from hunger became impaired. Hence, in 1986 an economic reform programme in the form of a Structural Adjustment Programme (SAP) was embarked upon anchored principally on the deregulation of the economy and liberalization of trade. The targets of these measures were principally the relaxation or abolition of import licensing, tariff structure, price control, foreign exchange control and interest rates control. Reform processes such as those embarked upon in Nigeria in 1986 usually leads to "a complete re-orientation of the economy" (Nwagbara, 2011) and this was indeed the case in Nigeria where the deregulatory and liberalization philosophy remains the critical basis of economic policy despite the official abandonment of Structural Adjustment Programme in the 1990s. Spurred by globalization, which itself is essentially deregulation on a global level, the Nigerian economy has since remained anchored on free-trade, market mechanism and private sector orientation, the key instruments of the SAP that ushered in the reform of the economic philosophy underlining the Nigerian economy in 1986. Although the shift to economic deregulation and trade liberalization affected many sectors of the economy, its impact on the agricultural economy was one of the most acute and remarkable (Ogbonna, 2012). The key features of agricultural production and the long tradition of governmental regulation of the sector became radically affected by the deregulation and liberalization philosophy with vital consequences for food security.

The specific policy instruments used included: abolition of commodity/ marketing boards, removal of subsidies on agricultural inputs such as fertilizers, reform of tariffs on the imports of agricultural inputs including tractors, liberalization of agricultural exports, and privatization of agro based enterprises, foreign exchange liberalization and interest rate deregulation (Adebayo, 2010). The idea of food security which was presented for the first time at the World Food Conference in 1974 viewed solely from the perspective of having adequate availability of food on a national scale.

There are four dimensions to this idea of food security, which include: (i) availability of sufficient amount of food which is a function of food production; (ii) stability of supply over time which depends on the ability to preserve/store produced food and supplement available food through imports if necessary; (iii) access to available food which depends on income levels and its distribution; and (iv) food utilization which encompasses procurement, ingestion and digestion. All these depend on nutritional quality, education and healthy being of the citizens (Horton and Steckel, 2013) which translate to food security that exists at both macro and micro levels. National Food Security (NFS) at the macro dimension is an index of the capability of a nation to procure enough food through production or imports to feed its entire population. This is a necessary condition but not a sufficient condition for Household Food Security (HFS) and Individual Food Security (IFS) since food availability on a national scale does not preclude the lack of adequate access to such food by many of the inhabitants due to weak markets, poor infrastructure and information system, and inequality in resource and income distribution (this is right to food and nutrition). Various composite indices that incorporate all the dimensions have since been developed to measure Food Security. Popular among these are the Aggregate Household Food Security Index (AHFSI) by the United Nation's Food and Agricultural Organization (FAO) and the Food Security Index (FSI) of the United States Agency for International Development (USAID). All these indicate that significant food and nutrition problems exist in Nigeria (FAO, 2012, 2015; NPFN, 2016) This is in terms of food supply and demand imbalance; the factors that constrain food supply and demand invariably affect food security.

In a nutshell, food security situation in Nigeria before and after the shift in economic philosophy is that while food supply improved considerably after deregulation, especially in the immediate post deregulation period, food accessibility and utilization worsened and overall food security status of the populace worsened. This conclusion, which aligns with those of other authors such as Adebayo (2010) and Ojeleye (2015), is a pointer to the fact that concerted efforts need to be made to halt further deterioration in the food security situation since, the economy is still managed based on the neo-liberal philosophy of *laissez-faire* that forms the basis of economic deregulation. However, since the poor state of food security emanates mainly from poor access to food, there is the need to implement policies that will raise the income of the low-income group, thereby, empowering them to access the diversity of available food. The policy measures that are required for this can come in various forms such as increasing the earning capacity of the poor through the adoption of pro-poor growth policies in which only those growth enhancing projects that have significant poverty reduction impacts, for example, through their employment creating effects are implemented, or the use of compensation programmes in nutrition (for example, free school meals), subsidized health care for women and children e.t.c. (NPFN, 2016).

## FOOD PRODUCTION AND MICROBIOLOGICAL PROCESSES- MY RESEARCH CONTRIBUTION

Microbiological processes have important roles in nearly all stages of food production. Therefore, scientific professionals usually make conscious efforts aimed at improving food security for the growing world population. This is part of the central focus of my research and recently the Society for General Microbiology, the Society for Applied Microbiology, the British Mycological Society and the British Society for Plant Pathology (all of which I am a member), released a mission statement that outlines some research themes through which Microbiologists can participate in food safety and security. These include:

- Soil health and nutrient cycling
- Plant–microbe dynamics

- Crop pathogens/protection
- Gut microbiology in farm animals
- Animal pathogens
- Food spoilage
- Food safety and human diseases

Two of these themes are the major focus of my research endeavour. These are: plant-microbe dynamics; and crop pathogens and protection. Based on my training in plant pathology and soil microbiology, the study of plants-some of their diseases, defenses and the microbiological processes involved in food production, has formed the bedrock of my intellectual interrogation from my academic infancy till date.

## INVESTIGATIONS ON PLANT-MICROBE INTERACTIONS

Plants represent a rich source of nutrients for many organisms including bacteria, fungi, insects, and vertebrates. Although lacking an immune system comparable to animals, plants have developed a stunning array of structural, chemical, and protein-based defenses designed to detect invading organisms and also stop such organisms before they are able to cause extensive damage (Hypersensitive Reaction). Understanding how plants defend themselves from pathogens and herbivores is essential in order to protect our food supply and develop highly disease-resistant plant species, and this is a new trend in Plant Pathology (Salami, 2017). Plant disease is any physiological abnormality or significant disruption in the "normal" health of a plant. Disease can be caused by living (biotic) agents, especially fungi or by environmental (abiotic) factors such as nutrient deficiency, drought, lack of oxygen, excessive temperature, ultraviolet radiation, or pollution.

In the course of my studies (Salami, 1999; 2000; and 2002), I discovered that many plant pathogens act like "silent thieves" who want to steal money locked inside a bank vault. Just as thieves use specialized tools designed to disable the bank's security system and unlock the vault without being detected, many pathogens in a similar way establish intimate relationships with their hosts in order to suppress plants' defenses and promote the release of their nutrients. Pathogens that keep their hosts alive and feed on living plant tissue are called biotrophs. Other pathogens resort to brute force like thieves who blast open a bank vault with explosives. These pathogens often produce toxins or tissue-degrading enzymes that overwhelm plant defenses and promote the quick release of nutrients (Odebode, *et al.*, 1995; 1997; Salami *et al.*, 2003). These pathogens are called necrotrophs, and examples include the gray mold fungus (*Botrytis cinerea*) and the bacterial soft-rot pathogens (*Erwinia carotovora*). Some pathogens are biotrophic during the early stages of infection but become necrotrophic during the latter stages of disease. These pathogens are called hemibiotrophs and include the fungus (*Magnaporthe grisea*), the causative agent of rice blast disease (Idowu *et al.*, 2013). Some pathogens live together and compete with one another, so that less nutrient will be made available to the less competitive one which will lead to its death and eventual elimination of the less competitive pathogen. These are referred to as antagonists, which could be resident or introduced in such interactions (Salami *et al.*, 2015; Salami and Odebode, 2005; Salami and Osonubi, 2003).

I have worked with fungi antagonists which are saprophytic soil fungi that are highly competitive and supported by bacteria and actinomycetes in the breakdown of pathogen infested plant refuse (Salami, 1999; Salami and Osonubi, 1999; Salami and Osonubi, 2003). I found that the mycelium and resting structures (i.e oospores and sclerotia) of several phytopathogenic soil fungi such as *Pythium* spp, *Phytophthora* spp, *Rhizoctonia* spp, *Sclerotium* spp and *Sclerotinia* spp were invaded, parasitized (mycoparasitism) or lyzed (mycolysis) by antagonistic fungi. Antagonism on plant surface involves mainly: Competition; Antibiosis; and Mycoparasitism (Salami, 1999; Idowu *et al.*, 2015; Salami, *et al.*, 2016). Each of these mechanisms has been demonstrated with the use of electron microscopy, cytochemistry and also the newest method, molecular biology. Antibiosis is the production of inhibitory metabolite or antibiotic by the antagonist in the rhizosphere for biological control. Competition occurs when two or more organisms have the same requirement for survival and the use of these requirements by one reduces the amount available to the other. One organism in this case, perhaps because of better uptake mechanisms or better extracellular enzymes, gets most of the nutrients and grows, while the other has too little to live on and then dies off (Salami, 2002; 2004; 2008). In these studies, competition for nutrients in the rhizosphere was found to be the likely mechanism for disease control. There is considerable evidence that competition for nutrients between pathogens and other soil micro-organisms plays a major role in suppressing the pathogen (Salami and Olawole, 2011; Salami *et al.*, 2011 and Oyetunji and Salami, 2011).

Mycoparasitism on the other hand refers to the phenomenon of one fungus parasitizing another or a necrotrophic mycoparasite found destroying the host's cell before or after invasion and then utilizing the nutrients from the dying or dead host (Salami, 2002; 2008). Some enzymes have been implicated as playing a major role in these interactions. These include the penetration of host's cell, secretion of cell wall-degrading enzymes such as cellulase which was found to be influenced by the presence of fungus or host wall components (Odebode, Salami and Osonubi, 1997; Salami and Osonubi, 2006). In our studies, *Trichoderma* spp showed hyphal parasitism by growing towards the hyphae, which, after the contact, formed coils and appresoria-like structures from which penetration took place. When the hyphae of *Trichoderma* spp were removed from host hyphae, pits and holes were seen indicating the action of cell wall degrading enzymes (Salami *et al.*, 2005a; b). This organism parasitized the mycelium and sclerotia of *Sclerotium* spp within 15 days while Salami (2002) found that *Trichoderma roseum* provided 100% inhibition of sclerotial germination after 30 days of co-incubation in soil. *Trichoderma* spp are also common soil inhabitants. They are major mycoparasites which parasitize a large number of plant pathogens (Salami and Osonubi, 2002; Odebode and Salami, 2004). They also produce antibiotics, therefore, they control many soil borne diseases such as damping off (Ladoye, 1993).

Salami *et al.* (2001; 2005) studied the interactions between *Glomus etunicatum* (mycorrhiza), *Phytophthora infestans* (pathogen), and *Trichoderma viride* (a soil-borne fungal antagonist) on pepper seedlings as it affects their growth and attested to effective biological control of this pathogen (Odebode *et al.*, 2001; Salami, 2002). This interaction was found beneficial to the plant in moderating the severity of disease incited on it by *Phytophthora infestans* (Salami, 2000). The efficiency of simultaneous and spatial inoculations of *T. koningii* and *G. mosseae* in the control of fusarium wilt disease of pepper and their effects on the cell structures of the infected plants was investigated by Salami (2008) while Oyetunji and Salami (2011) confirmed the effect of *T. koningii* and *G. mosseae* as antagonists. As a further confirmation of the ability of the antagonists in suppressing pathogenic infection, we also found that seedlings of pepper infected with *P.*

*aphanidermatum* recorded 56.67% infection rate, showing symptoms of stunted growth, chlorosis and wilting in the presence of *T. harzianum* and *T. viride* (Chang *et al.*, 2002; Salami *et al.*, 2011; Idowu *et al.*, 2016). Salami (2004) observed that *T. harzianum* and *T. viride* were able to reduce disease incidence of fusarium crown root rot in spite of the physical barrier between the antagonists and the pathogen. However, the infection rate reduced by 50-75% in the presence of *Trichoderma* species, which got the ability to reduce pathogenic infections (Salami *et al.*, 2015). This result corroborated Narasimha-Murthy *et al.* (2013) who reported that bacterial wilt disease incidence in *Trichoderma asperellum*-treated tomato seedling inoculated with *Ralstonia solanacearum*, produced healthier plant than when *Trichoderma* was absent and thus produced seedlings with about 50% reduction in infection rate under greenhouse conditions. *Trichoderma* species have been shown to reduce disease incidence of several pathogens by stimulating vegetative growth and enhancing the root development of the treated plants (Salami and Osonubi, 2006; Salami and Akintokun, 2008).

The reduction of disease infection rate and proportion, caused by soil borne pathogens after treatment with *T. harzianum* and subsequent enhancement in the yield of different crops have been reported by several workers (Oni, 2015; Idowu, 2017; Salami, 2017). This phenomenon was explained by Abd-El-Khair *et al.* (2010) who noted that application of *Trichoderma* species significantly reduced the disease incidence of damping-off disease caused by *Rhizoctonia solani* in cowpea. The efficacies of *Trichoderma* species in controlling post emergence *P. aphanidermatum* infection of pepper plants in screenhouse were evaluated and found to significantly increase the plant growth and development compared to the control. Analysis of stem height, root length, number of roots and dry weight of 30 day old seedlings, showed increased growth rate in the three *Trichoderma*-treated seedlings over control plants (Oni, 2015). The plant height values were higher in *T. atroviride* seedlings with or without pathogen than all other treatment combinations, although the presence of *T. harzianum* and *T. koningii* did not increase the height than when they were absent. Root length was longer in *T. atroviride* plus pathogen than in control and pathogen alone, but all other treatments with *Trichoderma* species, with/without pathogen, were not different from the control except for the pathogen alone. In the number of leaves produced by pepper plants, *T. koningii* with/without pathogen, *T. harzianum* alone produced more leaves than the control, while the pathogen alone treatment gave the least number of leaves. *T. atroviride* produced more roots than all others. In total fresh weight, however, *T. atroviride* and *T. harzianum treatments* outweighed the control, this was also the same in the seedlings stem and root dry weights, which showed that they contributed significantly to the pepper plant weight. The improved plant growth may be due to higher production of growth stimulators like Gibberellic acids and Indo-Acetic Acid which had been implicated in plant-*Trichoderma* interactions (Gravel *et al.*, 2015) or in the effort to reduce pathogens deleterious activities. In general, *Trichoderma* produced more vigorous and healthy seedlings (Kaveh *et al.*, 2011). The observed increase in plant growth after inoculation of the antagonist may be through the enhancement of the plant root system (Vinale, 2007; Idowu *et al.*, 2016). *Trichoderma* species, when added to soil or applied as seed treatment grow readily along with the developing plant root system; they have many positive effects on plant growth, yield, nutrient uptake, fertilizer utilization efficiency and systemic resistance to plant diseases (Narasimha-Murthy *et al.*, 2013; Idowu *et al.*, 2016; Gbadeyan, 2017).

Salami *et al.* (2016), reported that an individual bio-control agent may not sufficiently control wide spectrum of pathogens and that development of compatible combinations of control agents is a promising research direction. This cultivation has also been taken further for use in the area of bioremediation of polluted soils (crude oil and spent engine oil soil), where it was discovered that with the inoculation of mycorrhiza, bioremediation activities will be effected to salvage the deteriorating conditions for improved agricultural practices (Salami and Elum, 2010). I was the first to find and report that *P. pulmonarius* is a potential bioremediating agent in sites filled with organo-pollutants like crude oil. Sawdust can be used to cultivate this mushroom and thereafter, recycled in the process into a much useful Spent Mushroom Compost (SMC) which is an agricultural soil amendment. The work demonstrated, albeit on a small scale, that the mycelium and spent mushroom compost of *Pleurotus pulmonarius* are useful tools for bioremediation of crude oil polluted soil. Also, that a crude oil polluted soil undergoing bioremediation can be bio-stimulated with mycorrhiza in order to enhance high crop productivity which will eventually contribute to poverty alleviation and enhance food security. However, more work is still going on in this area especially as it relates to in-situ application and long-term studies of the associated crops and soil types.

## MICROBES: FRIENDS OR FOES?

Microbes are everywhere even though we cannot see them. These microscopic organisms play a very important role in our lives (Salami and Elum, 2010). Some cause diseases and thus, make us sick but the majority are completely harmless while many are more helpful (Salami, 2004). In fact, we cannot live without them, but they can live without us (Salami and Osonubi, 1999). Microbes are very diverse; they have an amazing variety of shapes and sizes, and they can exist in a wide range of habitats including the bodies of animals and plants. Microbes live in the soil and the rocks - just think, every time you walk on the ground, you step on millions of microbes. Microbiologists study microbes: where they occur, their survival strategies, how they can affect us and how we can explore or exploit them for our benefits. Microbes are very small living organisms, so small that most of them are invisible. The majority can only be seen with a microscope, which magnifies their images so that we can see them. In fact, microbes are so tiny you would find over a million in a teaspoon of soil! They make up more than 60% of the earth's living matter and scientists estimate that 2-3 billion species share the planet with us (Salami *et al.*, 2016).

In order to find out more about microbes/microorganisms, we need a peek down the microscope. These microscopic organisms play important roles in maintaining life on earth, fixing gases and breaking down dead plant and animal matter into simpler substances that are used at the beginning of the food chain. Biotechnologists can also exploit the activities of microbes to benefit human beings, such as in the production of medicines, enzymes and food (Salami and Akintokun, 2010). These micro-organisms are also used to breakdown sewage and other toxic wastes into safe matter. This process is called bioremediation which is part of what was achieved in the course of my research work (Salami and Elum, 2010; Salami and Owasoyo, 2016; Salami and Adebiyi, 2017). Micro-organisms occur in an amazing variety of shapes and sizes and they are of different types such as:

## 1. Bacteria

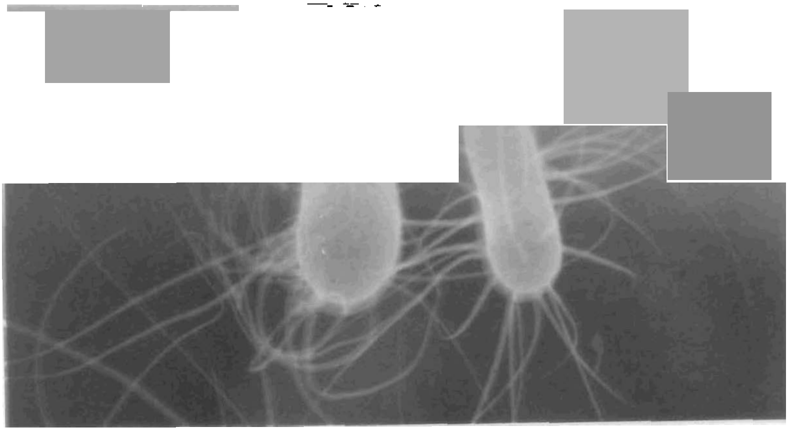


**Plate 1 showing bacteria microbes.**

## 2. Viruses

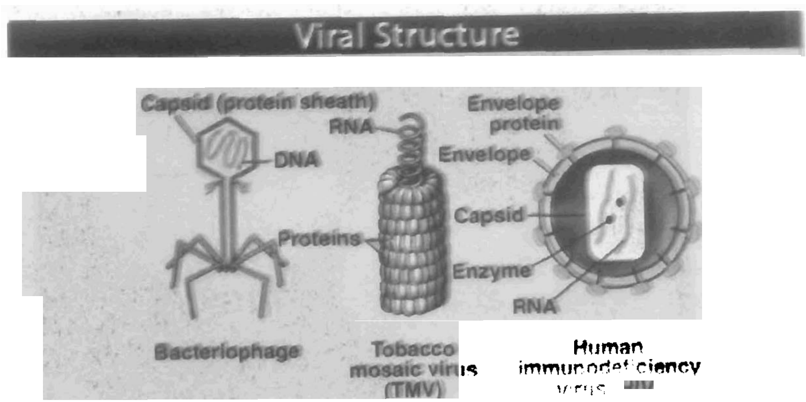



**Plate 2: Viral structure**

## 3. Protozoa

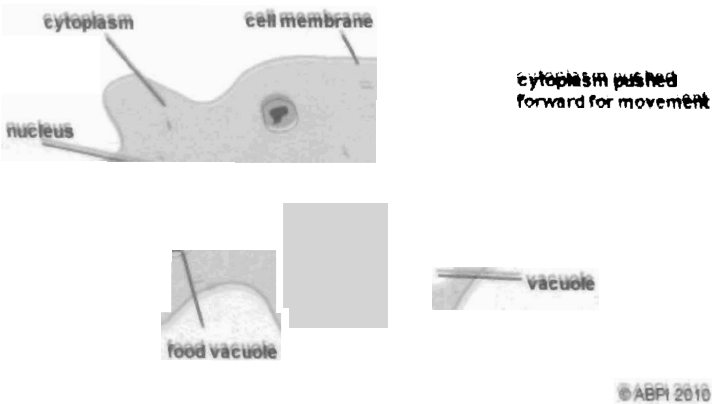



Plate 3: Protozoa structure

## 4. Algae

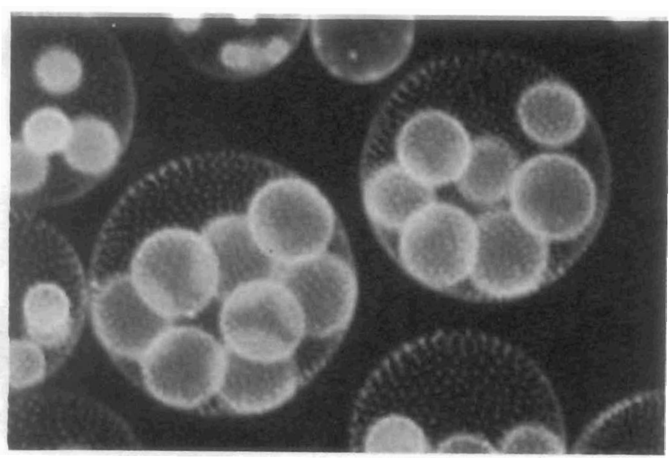


Plate 4: Structure of Algae

## 5. Fungi

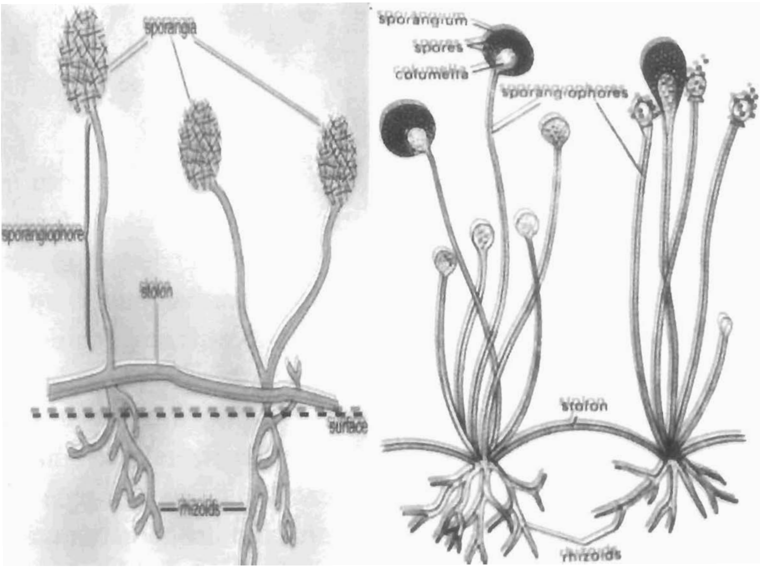



**Plate 5: Fungi structure**

## MICROBES AND FOOD

The microbes associated with our food tend to have a bad name – food poisoning, and are often in the news. Yet, while some make us ill and others nuisance that spoil our food, without the activities of these microbes there would no bread, cheese, beer or chocolate. Friend or foe – food microbes are always on the menu. This is when they act as producers, by fermenting sugar to make energy for themselves and in the course of this, they produce for us food like bread and yoghurt which can only be made by microbial fermentations. Meanwhile, bread yeast - *Saccharomyces cerevisiae* is used to make bread. Yeast is a single-celled fungus. It is able to ferment sugar; producing alcohol and carbon dioxide in the process. It has long been used to make beer and wine as well as bread (the carbon dioxide causes the dough to rise).

Some fungi and soil bacteria, called the decomposers, break down dead plant and animal tissues into simpler substances, called nutrients. These nutrients, including carbon dioxide, water, sodium and potassium are returned to the environment so that other living things can use them. This cyclical process by which essential elements are released and reused is known as recycling. All essential elements such as carbon and nitrogen are cycled through biochemical pathways.

## MICROBES AS SPOILERS

Microbes can be categorized as spoilers especially when they grow on food, and such food soon begin to smell bad, look slimy, change colour, taste awful or even get a furry coating and thus, it is no longer edible. This could be referred to as food poisoning. There are probably at least a million cases of microbial food poisoning in many places every year costing a huge loss to the economy. How can something as small as a microbe cause all these troubles? Microbes like all living organisms need food for energy and growth. Sometimes microbes get in or on our food and break it down to provide themselves with energy and nutrients. Microbial growth causes the food to look, taste, and/or smell disgusting. The food becomes unfit for human beings to consume hence, it must be thrown away. They could also be referred to as mouldy fruit.

A mould is a type of fungus. Fungal spores (these are like the seeds of a plant) are all around us in the air. These spores can land on the fruit. If it is warm and moist the fungal spores grow. They send out very fine thread-like structures called hyphae. The yellow fibrous structures are hyphae, which make up the main body of the fungus. They penetrate the bread and absorb nutrients. The small green dots are the conidia, the spores of the mould. The moulds that grow on fruit and vegetables produce enzymes that weaken the protective outer skin, thereby, allowing penetration by the hyphae. The hyphae grow down into the fruit, digest it and absorb the nutrients. These threads criss-cross each other to form a large tangled structure known as a mycelium. The hyphae produce stalks that grow upwards and the spores formed at the end of the stalks are released into the air to start the process over again. Eventually the fruit is covered in a furry coat and it is not fit to eat.

## FUNGI

Fungi can be single-celled or very complex multicellular organisms. They are found in any habitat but most of them live on land, mainly in soil or on plant material rather than in sea or fresh water. A group of fungi, called the decomposers, grow in the soil or on dead plant matter where they play important role in the cycling of carbon and other elements. Some are parasites of plants causing diseases such as mildews, rusts, scabs or canker (Salami *et al.*, 2016a). In crops, fungal diseases can lead to significant monetary loss for the farmer. A very small number of fungi cause diseases in animals and in human beings, these include skin diseases such as athletes' foot, ringworm and mouth thrush. Fungi are members of a large group of eukaryotic organisms that includes microorganisms such as yeasts and molds, as well as the more familiar mushrooms. They are a group of unicellular, multicellular, or syncytial spore-producing organisms feeding on organic matter and they include: mushrooms (Salami *et al.*, 2016b), moulds, mycorrhizae, yeasts, rusts, etc. Fungi are relatively unseen but important components of the environment, together with the microscopic bacteria, protozoa, and micro-fauna they are key members of any terrestrial community whether it is a whole forest or a flower pot.

Science has traditionally classified biotic organisms or living things as either plant or animal. But I wish to submit that from strictly scientific point of view, fungi are neither animals nor plants (Omomowo and Salami, 2017)! Perhaps, at best, they may be regarded as pseudo-plants. They are similar to plants because of the presence of cell-wall, but they have no chlorophyll and cannot make their own food like typical plants can, through the process of photosynthesis. They get their food by absorbing nutrients from their surroundings. Fungi and animals digest other organisms to obtain energy and other nutrients. Animals typically 'eat' food and digest it internally whereas fungi undergo external digestion! They literally grow through their food secreting enzymes outside of their cells and absorbing the breakdown products.

For a long time, fungi were classified as plants, mainly because of their similar lifestyles - both are seen to grow in soil and are sessile (permanently attached; not moving). Plant and fungi cells have cell walls, while cells from the animal kingdom do not have. Fungi are thought to have diverged from the plant and animal kingdoms about one billion years ago (Ladoye, 1993). Fungi are subdivided on the basis of their life cycles, the presence or structure of their fruiting bodies and the arrangement and type of spores (reproductive or distributional cells) they produce. These three major groups of fungi are: multicellular filamentous moulds; macroscopic filamentous fungi that form large fruiting bodies (sometimes the group is referred to as 'mushrooms', but the mushroom is just the part of the fungus we see above ground which is also known as the fruiting body) (Salami *et al.*, 2017); and the single-celled microscopic yeasts.

# FUNGI AS FOOD

## MUSHROOM PRODUCTION

Mushroom is the fleshy, spore-producing fruiting bodies of some higher fungi. Mushrooms are saprophytes and they include members of the Basidiomycota and some members of the Ascomycota (Bankole, 2012; 2017). They are found growing on damp rotten log of wood trunk of trees, decaying organic matter and in damp soil rich in organic substances (Elum, 2010). Edible mushrooms are highly nutritious and can be compared with egg, milk and meat (Salami *et al.*, 2016; Ogbonnaya, 2017). Salami *et al.* (2016; 2017) confirmed that edible mushrooms have high nutritional attributes and potential applications in industries. Mushrooms are considered to be one of the efficient proteineous food (Salami and Bankole, 2016). Therefore, mushrooms can be good supplement to some cereals and legumes (Okoro, 2012; Salami *et al.*, 2017). Protein content of mushroom varies from 4-44% depending on the species (Oei, 2003; Salami *et al*, 2016; 2017), whereas, the other foods like beef and wheat contain protein of about 16 and 1% respectively (Oei, 2003). Mushroom is not grown directly on soil like crops but on organic substrate, either raw or composted. A substrate is any substance that can facilitate mycelia growth. These substrates are mostly materials from farm, plantations or factories. Several substrates have been used in the production of oyster mushroom and these include single agro-wastes such as dry banana leaves, sugarcane bagasse, maize straw, and oil palm spadix, corn cobs, sawdust, combination of agro-wastes such as corncobs and groundnut shell, corncobs with rice bran, sugarcane bagasse with rice bran and sugarcane bagasse with groundnut shell (Salami *et al.*, 2016; Salami *et al.*, 2017; Bankole and Salami, 2017).

## TISSUE CULTURE PROCESS

Mushroom can also be cultivated through tissue culture. Little portion of the mushroom's cap are washed in 1% parazone for five minutes. These portions will then be transferred to a pair of filter paper to drain the water droplets from the mushroom. Aseptically in the laminar flow, the tissues on the filter will be transferred unto Potato Dextrose Agar (PDA) Plate and incubated for 3 days at 28°C and thereafter, stored in the slant bottles for future use. This is usually an expensive procedure due to the high cost of synthetic PDA used which might be unaffordable for ordinary farmers that may be interested in mushroom production. To address this constraint, Bankole and Salami (2017) investigated the use and potentials of different growth media for the tissue culture process of oyster mushroom. The results of this investigation were positive as the agro-waste media supported the growth of the organism at the tissue culture stage with no significant difference from the conventional growth media (PDA) used as control for the study.

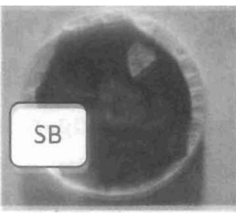



Plate 6a: Mycelia of *P. florida* on SCBA 72hrs after inoculation

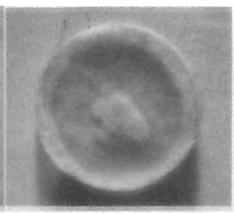


Plate 6b: Mycelia of *P. florida* on PDA 72hrs after inoculation

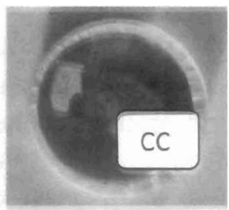



Plate 6c: Mycelia of *P. florida* on CCA 72hrs after inoculation

## SPAWN PRODUCTION

The mushroom seed is generally referred to as "spawn". Spawn is the living ramified mycelium of a typical mushroom, multiplied on a suitable sterile base material under aseptic condition. Spawn of the mushroom is usually produced using sorghum grains. The grains were washed and parboiled for about 30 minutes after which they were decanted and allowed to cool. Calcium carbonate was then added to regulate the pH of the grains. Labelled, sterilized jam bottles were filled with these grains up to about ¾ of the size of the bottle (Salami *et al.*, 2017). Further to this, Bankole and Salami (2017) developed a protocol which utilizes agro-wastes rather than food crops for the production of spawns which drastically reduce the cost of production, the time taken for production and the dependence of the mushroom industries on food crops most especially the cereals.

Plate 7a: Sterilized bottles containing agro-waste combination

Plate 7b: Fully ramified spawn bottles agro-waste combination

## FRUITING BODY PRODUCTION

Salami *et al.* (2016) established the production of mushroom using agro-wastes and reported differences in the yield and nutritional status of the fruiting bodies with respect to the different substrates (agro-wastes) used.

Each substrate was poured into a clean bowl and 2-3% of calcium carbonate ($CaCO_3$) and calcium hydroxide $Ca(OH)_2$ were added for optimization and adjustment of the pH to a range of 5.5-8.5 for optimum mycelial colonization. The different ratio of the combination of calcium hydroxide and calcium carbonate investigated for optimum yield affected both the spawn production and the final fruiting body production. Four percent [4%] (1% $CaCO_3$ and 3% $CaSO_4$) of the calcium additives was effective for reducing the days to full ramification of the substrates for spawn production from two weeks to an average of seven days (Bankole and Salami, 2017). On the other hand, 5% calcium augmentation (1 % $CaCO_3$ and 4 % $CaSO_4$) was best for the production of *P. florida* fruiting bodies (Bankole, 2017). In the course of my studies, I have found that combination of different substrates for the production of oyster mushroom also showed a synergistic effect in that, the combined substrates complemented each other in supplying nutrient for the growing organism. Thereby, improving the yield and also raising the nutritional qualities of the mushroom. The yield and nutritional qualities of the mushroom from these combined substrates were found to be significantly different from the uncombined substrates.

With this improved technology, mushroom primordial initiation was shortened to an average of 21- 28 days as against an average of 20–35 days previously established for the primordial initiation as reported by (Naraian *et al.*, 2009). This result showed that the technology delayed initiation by a day but shortened completion by seven days thus, reducing the entire days of production. It was therefore, recommended that mushroom production should be increased with the use of agro-wastes from farm produce. Also, combination of agro-wastes in place of single substrate are recommended for the entire production of *P. florida* without the use of any edible food materials such as cereals. Augmentation of substrates with calcium sulphate and calcium carbonate within the range of 4-5 % is recommended for successful production of oyster mushroom *P. florida*.

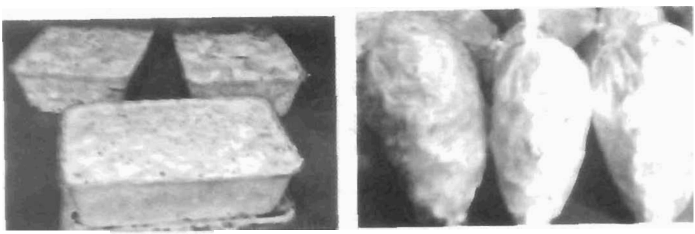


Plate 8: Ramified substrates of *P. florida* (oyster mushroom)

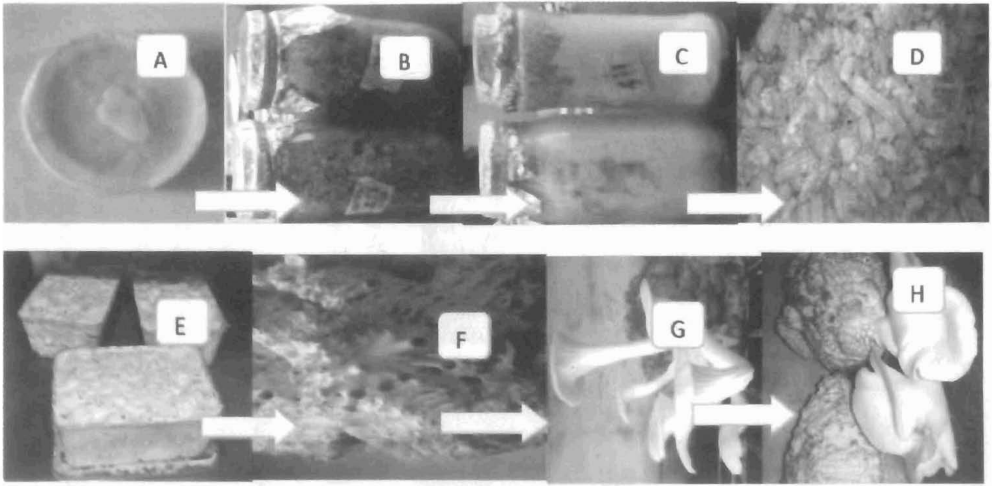



Plate 9: Different stages in Mushroom production
A-Tissue culture, B: Sterilized bottle of agro-wastes, C- Completely ramified spawn bottles, D- Chopped agro-wastes substrates, E -Completely ramified substrates, F -Pin head formation on ramified substrate, G&H -Matured fruiting bodies.

Human beings have been eating fungi since time immemorial. Today, we eat an enormous quantity of a wide variety of edible fungi, including truffles, mushrooms, shitake and many others. We also use fungi, e.g. yeast, in food manufacturing for the fermentation of wine, beers and other alcoholic drinks. We add yeast to dough to make bread rise when we bake it. Numerous fungi form various kinds of fruiting bodies which we call mushrooms or toadstools, brackets, puffballs, etc. Many mushroom fruiting bodies are short-lived (Salami *et al.*, 2016) and seem to appear overnight. Collecting mushroom is somewhat analogous to plucking apples from apple tree. The mushroom is a temporary reproductive structure or fruiting body of the much larger individual living in the soil or log. Unlike animals, fungi reproduce by spores (Bankole, 2017). These microscopic cells spread by air, water, or animals, allow the fungus to start growing in a new location or food source. Many fungi, such as yeasts, molds on food, powdery mildews on plants, athlete's foot fungus, and other beneficial soil fungi, do not form visible fruiting bodies, their spores are produced on microscopic structures.

There is however also a dark side to food microbiology and microorganisms which can have serious detrimental effects on food production. The spread and evolution of food pathogens is a growing problem for crop yield and consumer safety. As exemplified by different outbreaks of disease infections in every part of the world, microbial food contamination remains a major problem. It is impossible to eliminate microorganisms from agricultural products and therefore, they play important roles throughout the food processing chain. Thus, these food microbes are of great social and economic importance.

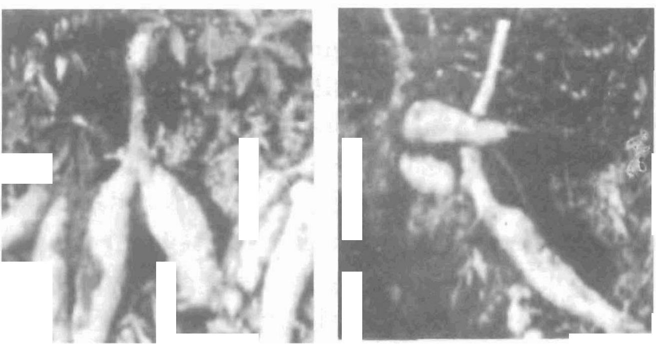
Many types of antibiotics come from fungi, such as penicillin (*Penicillium chrysogenum*), cephalosporin (*Acremonium* spp) and griseofulvin (*Penicillium griseofulvin*). Fungal antibiotics are extensively used for treating tuberculosis, syphilis, and leprosy diseases. Some form of chemotherapy use fungi, for instance, lentilan drug is sourced from the shiitake mushroom and it is used for cancer treatment.

Fungi are also used in the production of ethanol. They are used extensively to produce industrial chemicals, such as citric acid, gluconic acid, malic acid, and biological detergents. They are used in bioremediation (Salami and Elum, 2010; Salami and Imoni, 2015) - the detoxification of polluted water or soil (Salami and Adebiyi, 2017). Fungi are also used in agriculture for pest control and to protect crops from diseases (Idowu *et al.,* 2016). Symbiosis is when one living thing builds up a relationship with another for the mutual survival of both. Some fungi form mycorrhizae which enhance the root of plant's capacity to absorb nutrients; hence, they are referred to as Mycorrhizae or Mycorrhizal Fungi. The plant synthesizes nutrients the fungus needs and exchanges these nutrients for minerals the fungus aids the plant to uptake nutrients from the soil - i.e. the plant and the fungus trade nutrients. Mycorrhizae are the word for the tangle of tissue that forms when certain treads specialized soil fungi get together with plant roots. It is an evolving relationship of about 400-million-year-old. The infection of feeder roots of most food crops by symbiotic fungi and the transformation of these root into unique morphological structures called mycorrhizae which are root fungi, undoubtedly constitutes one of man's persistent and interesting use of bio-control technology. Most of these food crops are of economic importance to man and they are in symbiotic association with mycorrhiza (Odebode *et al.*, 1995, Osonubi and Salami, 2003). Mycorrhizae are everywhere in relatively undisturbed soils more than 90 percent of the world's plants form them around or inside the root cells. The more numerous ecto-mycorrhizal species (Ecto- is a prefix meaning "outside") attach themselves to the outsides of root cells of conifers (Odebode *et al.*, 1995). The other major category, endo-mycorrhizae, colonize root tissue from inside the cell. These species associate themselves with non-coniferous plants, such as shrubs, herbs, and grasses, including most of the commercially important ornamental and agricultural plants. Most undisturbed, natural settings have abundance of mycorrhizae? But disturbed soils, like construction sites or heavily compacted logging sites, or sites where trees are growing in lawns treated with chemicals, are the places where the mycorrhizae are depleted, and the plants suffer (Salami and Osonubi, 1999; 2006).

## MYCORRHIZAL FUNGI

Mycorrhizal fungi are symbioses between plants and beneficial soil fungi like arbuscular-mycorrhizal fungi (AMF) that are known to promote plant growth and help plants to cope with biotic and abiotic stresses (Idowu *et al*, 2016; Salami, 2017). My studies have provided an overview of the impact on interactions between mycorrhizal plants and pathogens as well as synthesis of the current knowledge of the underlying mechanisms (Salami, 2007; Awotoye *et al.*, 2009; and Adewole *et al.*, 2010). My focus is on the priming of plant defense mechanisms that play a central role in the induction of resistance by arbuscular mycorrhizae. These studies were carried out under different methodological approaches in order to provide a broad understanding of the underlying mechanisms. For instance, Salami (2002; 2004; 2008) studied the effects of the arbuscular mycorrhizal fungus, *Glomus clarum* on disease severity of *Sclerotium rolfsii* on tomato and pepper. Single inoculations of the mycorrhiza and the pathogen on the seedlings of plants were compared with simultaneous, as well as relay inoculations of both organisms; and their effects on disease severity and consequent growth on the plants were determined (Salami and Odebode, 2004). The results showed the clear advantage of inoculating the plants with mycorrhiza first before infection by the pathogen, in conditioning the plants for resistance. The real beauty of these mycorrhizal fungi, as they are called, is more than skin-deep. As mycorrhizae connect with the roots of plants, they can increase the plant's ability to take in water and nutrients by 10 to 1,000 times. This study revealed how mycorrhiza enhanced the quality of the farm produce by using yield components as parameters for evaluating the treatment effects (Salami and Osonubi, 2006; Salami and Olawole, 2011; Salami *et al.*, 2011).

Mycorrhizal associations with plants enhance nutrient uptake, growth and induction of disease resistance within the benefitting host plants (Ladoye, 1993; Odebode *et al.*, 1995; and Salami, 1999). These studies draw attention to cases where mycorrhizal association with crops have been shown to improve crop performance substantially, and the possibility of exploiting such mycorrhizal technology to enhance agricultural production (Salami, 2007; Salami and Osonubi, 2006). Likely problems that might be encountered in the adoption of the technology were discussed and solution proffered. This same methodology was experimented with peasant farmers through participatory approach. This engagement with the farmers was conducted over a period of 3 years and it resulted in improved yield of crops (such as cassava tubers, cowpea) with high income for these resource poor famers. On the basis of the success recorded in this engagement, I was contacted by Acres for Life in Providence Design and Development, 139 Kelton Court, Simi Valley, C A 93065, U.S.A. to replicate the same approach in some local communities in Uganda, East Africa. This was done with great success in 2006. The results of this experiment with farmers were submitted at the continental level as an entry in the 1st International Awards in African Women in Science Competition in 2009 and the submission was adjudged a Winner. The results, which were well celebrated and published in *Agricultural Innovations for Sustainable Development*, were from the appraisal of the adoption of an Agro-biotechnology System for Improving Traditional Land-use System in Sub-Saharan Africa by the resource poor farmers in south western Nigeria. It was demonstrated that VAM inoculation with application of legume-tree mulching can adequately substitute for NPK fertilizer application as it produced significantly higher tuberous root yield than un-inoculated cassava in alley cropping (Salami, 2009).



A: Mycorrhizal cassava tuber

B: Non-mycorrhizal cassava tuber

Plate 10: Effects of mycorrhizal inoculation on yield and health of root tubers

Mycorrhiza also helps plants to strengthen their immune systems and this has also been proven in my study and collaborative work with other colleagues. We reported a study on the effects of the mycorrhizal fungus, *Glomus deserticola* on infection of pepper by *Pythium aphanidermatum*. Influence of arbuscular (AM) fungus *Glomus deserticola* on disease severity and growth of pepper seedlings infected with *Pythium aphanidermatum* was investigated in the sreenhouse (Odebode *et al*., 1995; 1997; Salami, 2000; Awotoye, 2009; Adewole, 2010). Pepper seedlings inoculated with the pathogen alone died while pepper seedlings simultaneously inoculated with mycorrhiza and pathogen or dually inoculated with mycorrhiza two weeks before pathogen inoculation suppressed the disease symptoms (such as chlorosis, defoliation, flower abortion and fruiting). Other growth parameters such as leaf number, plant height, diameter and shoot dry weight of simultaneously inoculated plants were found higher than the uninoculated controls or plants without mycorrhizal inoculation (Odebode *et al*., 1997). The significance of this study is that simultaneous and dual inoculations of pepper plants prevented damping-off of young seedlings and also reduced the severity of disease incidence. They emit chemicals into the soil to unlock hard-to-extract micronutrients like iron and phosphorus. They produce organic "glues" that make the soil more clumpy and porous, thereby improving its structure and resilience (Ladoye, 1993). Other studies conducted on immune strengthening potential of mycorrhiza include: jute mallow and okra by *Fusarium spp.* (Salami and Olawole, 2011); and *Pythium aphanidermatum* and Okra (Salami *et al.*, 2012). This methodology of having single, simultaneous and dual/concomitant inoculations has also been taken far outside the shores of Nigeria to the United States of America where United State Department of Agriculture Agricultural Research Services, Northern Plains, Agricultural Research Laboratory in Sidney, Montana, USA (USDA ARS NPARL) invited me as an International Visiting Research Scholar (Government Visitor). The invitation was to collaborate on Plant-Microbe-Interaction Research and the results of this research have been adopted by USDA and subsequently journal publication in America Phytopathological Society (APS).

## MYCORRHIZA-INDUCED RESISTANCE AND PRIMING OF PLANT DEFENSES

Symbiosis between plants and beneficial soil microorganisms like arbuscular-mycorrhizal fungi (AMF) are known to promote plant growth and help plants to cope with biotic and abiotic stresses (Awotoye *et al.*, 1992; 2009; Adewole *et al.*, 2010). Profound physiological changes take place in the host plant upon root colonization by AMF which affect the interactions with a wide range of organism below- and above-ground. Protective effects of the symbiosis against pathogens, pests, and parasitic plants have been described for many plant species, including agriculturally important crop varieties (Salami and Osonubi, 2007; Oyetunji and Salami, 2011). Besides mechanisms such as improved plant nutrition and competition, experimental evidence supports a major role of plant defenses in the observed protection (Salami and Osonubi, 2002, Salami *et al.*, 2001). During mycorrhiza establishment, modulation of plant defense responses occurs thus, achieving a functional symbiosis (Salami, 2002; Salami and Osonubi, 2003). As a consequence of this modulation, a mild, but effective activation of the plant immune responses seems to occur, not only locally but also systemically (Odebode and Salami, 2004). This activation leads to a primed state of the plant that allows a more efficient activation of defense mechanisms in response to attack by potential enemies (Salami, 2017). Here, we give an overview of the impact on interactions between mycorrhizal plants and pathogens, parasitic plants, and we summarize the current knowledge of the underlying mechanisms. We focus on the priming of plant defense mechanisms that play a central role in the induction of resistance by arbuscular mycorrhizas (Salami, 2009).

Plants respond to different associations in different ways, depending on the nature of the associations (Salami, 2017). The association of soil-borne pathogens with plants is parasitic; because such pathogens destroy the living roots of plants and also make use of them as their main source of food. These soil-borne pathogens disorganize the tissues of their hosts (plants) in the process, resulting in plant diseases such as root-rot (Lartey and Salami, 2013). The roots on the other hand become rotten and fibrous. The basis for this pathogenesis is the secretion of cell wall degrading enzymes by pathogens (Oluma, 1992; Salami, 1999, Salami and Akintokun, 2010). The result of our study on the production of cell-wall degrading enzymes in *Glomus etunicatum* (mycorrhiza) association with pepper plant confirms the involvement of these enzymes as infectivity factors in the establishment of the association formed (Salami *et al.*, 2001). It further proved the production of cell wall degrading enzymes by *G. etunicatum* through the reduction in plant growth and attainment of chlorotic symptoms at the early stage of mycorrhizal infection, a physiological effect that disappeared as soon as the mycorrhiza established itself in the inoculated plant (Odebode *et al.*, 2001). We also studied the activities of the enzymes, cellulase and catalase in pepper seedlings that have been inoculated with mycorrhiza fungus, *Glomus etunicatum* and/or the pathogen, *Phytophthora infestans* with a view to elucidating the probable roles of the enzymes in moderating disease infection in host plants subjected to mycorrhizal association. Activity of these enzymes was found to increase as the age of pepper seedlings increased in order to show in-built resistance together with higher phenolic compound activity in the infected tissues of the resistant plant (Salami *et al.*, 2005). We have also researched the roles of the oxidative enzymes, polyphenol oxidase, peroxidase and catalase in moderating infection by *Phytophthora infestans* on pepper seedlings subjected to mycorrhizal association with *Glomus etunicatum* (Salami, 2000). The results showed that pepper seedlings inoculated with *Phytophthora infestans* alone had increased levels of oxidative enzymes, while pepper seedlings inoculated with *Glomus etunicatum* alone or simultaneously with *Phytophthora infestans* had decreased levels of oxidative enzymes. This shows the protective effect of the mycorrhizal association against infection by *Phytophthora infestans* in the pepper plants (Salami *et al.*, 2001). Also, part of my research efforts are directed towards elucidating mechanisms of pathogenicity of fungi that pose a threat to important staple crops such as wheat, barley (USDA, 2012), maize and rice.

## FOOD SECURITY AND THE AMAZING ROLE OF FUNGI

Agricultural production is critical to the eradication of hunger, malnutrition and respond to the nutritional demands generated by global population growth. My goal is to advance our understanding of the bio-control effects as well as the edibility and palatability of some fungi micro-organism. Such fundamental knowledge will aid development of sustainable strategies to minimize losses in food production due to plant disease. My research efforts are directed towards elucidating mechanisms of pathogenicity of fungi that pose a threat to important staple crops such as cassava, wheat, barley (USDA, 2012), maize, soy bean, rice and vegetables such as pepper, tomato, okra, jute mallow and amaranthus (Salami and Olawole, 2011). I am primarily interested in the discovery of fungal effectors (i.e. proteins molecules secreted by fungi), molecules that allow the pathogen to manipulate the host by changing its metabolism & physiology and then establish a compatible interaction with the plant. Conceptually, a reduction in translocated effectors should result in decreased virulence by pathogens and improved disease resistance of the infected plant. Because many effectors are, in principle, targeted, it would be difficult for multiple effectors to simultaneously hijack one of the several other pathways for cell entry. On the other hand, constitutive expression of a protein effector to block cell surface may alter the development and physiology of the plant and or interfere with effector proteins required for beneficial plant microbe interactions (Odebode and Salami, 2004). Controlling the timing and site of deployment of effector blocking molecules may be key to successfully implementing the mycorrhizal biotechnology in field settings. This is in order to maximize yield and protection, hence, the trial of different methods of inoculations in different studies (Ladoye, 1993; Salami, 1999; Salami, 2000; Salami and Osonubi, 2002).

Pathogenic and beneficial fungal symbiosis affects the productivity of many economically important plant species and even animals and human beings. Pathogenic fungi cause important plant diseases which include rice blast (Idowu *et al*, 2013), soybean rust and root rot, late blight diseases and conversely, beneficial mycorrhizal fungi improve disease; drought resistance; and nutrient uptake by plants (Salami *et. al.*, 2001; 2005; 2011). Through convergent evolution, these micro-organisms, especially fungi, have acquired striking similarities in their mechanisms of host colonization, including physiological adaptations, mechanisms of adhesion, modulation of host defenses, and strategies of nutrient acquisition (Lartey *et al.*, 2013; Lartey and Salami, 2013). Many symbiotic microbes manipulate their hosts' physiology through the use of secreted effector proteins (Salami and Osonubi, 2006). Some effectors act in the apoplast, while others translocate into host cells (Salami *et al.*, 2005). To get a comprehensive view of the molecular events that dictate disease susceptibility or resistance, my laboratory seeks to integrate the molecular and mechanisms of these fungal effectors and plant resistance-associated networks. We directly seek to acquire knowledge of their mechanisms of action and the manner in which these mechanisms relate to the lifestyle of both mutualistic and pathogenic fungi in order to address the menace of hunger. Fungal experts have discovered that networks of microscopic fungi play a key role in aiding plants to extract nutrients from the soil. These networks, which have been christened "nature's internet" have been completely destroyed in much of the world. Recent studies have also shown that these complex fungal networks (mycorrhizae) can help plants to fight off disease and can even allow for the flow of nutrients from one plant to another, even over large distances (Salami *et al*., 2011; Lartey *et al*., 2013). A combination of intensive farming, fertilizer and human intrusion have destroyed these networks across the world despite the accumulating evidence of how vital these fungi are for growing crop and how they are intimately connecting with plants for growth (Salami, 2004; Salami and Osonubi, 2007).

At present, virtually all world agriculture is built on the use of large amounts of industrialized nitrogen fertilizer, which is very expensive. As global oil supplies dwindle, finding replacement for fertilizer is considered by many to be the biggest challenge facing the world's agricultural community over the next 50 years (Yadav *et al*., 2013; Kutama *et al*., 2013). This has prompted Universities and research institutions to examine the role that the mycorrhiza fungal networks could have on world agriculture. Biotechnology, which often uses microbes or their products, is a fast-growing area of science. Hence, as a Mycologist, I have worked with plants interacting with the biotechnology fungi (i.e. both as pathogens and beneficial organisms, amongst which are; bio-control agents; mycorrhiza (endomycorrhiza/Arbuscular

Mycorrhiza); and mushroom). My studies (Salami and Bankole, 2016; Idowu *et al.*, 2013; Salami *et al.*, 2015; 2016) have shown that plants have their own defenses both chemically and structurally. These findings have also been conveyed to some other Scientists in Nigerian Society for Plant Protection (NSPP) where I was invited as lead paper presenter in the year 2014. Plants have developed multiple layers of sophisticated surveillance mechanisms that recognize potentially dangerous pathogens and rapidly respond before those organisms have a chance to cause serious damage. These surveillance systems are linked to specific pre-programmed defense responses. Basal resistance, also called innate immunity, is the first line of pre-formed and inducible defense that protect plants against entire groups of pathogens. Basal resistance can be triggered when plant cells recognize microbe-associated molecular patterns (MAMPs) including specific proteins, lipopolysaccharides, and cell wall components commonly found in microbes. The result is that living plant cells become fortified against attack. Non-pathogens as well as pathogens are capable of triggering basal resistance in plants due to the widespread presence of these molecular components in their cells. Pathogens have developed counter measures that are able to suppress basal resistance in certain plant species (Salami, 2017). If a pathogen is capable of suppressing basal defense, plants may respond with another line of defense: the hypersensitive response (HR).


Plate 11: Hypersensitive response lesion on an Arabidopsis leaf

The HR is characterized by deliberate plant cell suicide at the site of infection. Although compared to basal resistance, the HR may limit pathogen's access to water and nutrients by sacrificing few cells in order to save the rest of the plant. The HR is typically more pathogen-specific than basal resistance and it is often triggered when gene products in the plant cell recognize the presence of specific disease-causing effector molecules introduced into the host by the pathogen. Bacteria, fungi, viruses, and microscopic worms called nematodes are capable of inducing the HR in plant. Plants also respond to pathogenic infection through mechanical injuries by the accumulation of toxic chemicals which could be mostly phenolic. Also, following infection of plant tissues or injury, phenols appear to play an important role in inhibiting enzymatic hydrolysis, indirectly inhibiting microbial development which in the process of.repair, causes translocation of these phenols to the site of infection (Salami, 2017). All these responses by plants allow for change in the level of its biochemical contents as well their activities (Odebode *et al.*, 2001a). It was further noted in our work that these interactions lead to production of α-β- glycosidase which was further oxidized by this phenol oxidase to quinones that are highly toxic to the pathogens (Odebode *et al.*, 2001b; Salami *et al.*, 2001). Plants generally have these substances in their system but it is usually triggered in the resistant varieties while the chain of this defense reaction is not triggered in the susceptible varieties (Salami, 2002; Odebode and Salami, 2004; Salami and Popoola, 2006).

Once the hypersensitive response has been triggered, plant tissues may become highly resistant to a broad range of pathogens for an extended period of time. This phenomenon is called systemic acquired resistance (SAR) and represents a heightened state of readiness in which plant resources are mobilized in case of further attack. As researchers, we have learnt to artificially trigger SAR by spraying plants with chemicals called plant activators. In the past, these substances gained favour in the agricultural community because they were considered much less toxic to human beings and wildlife than fungicides or antibiotics, and their protective effects can last much longer. Disease problems and management are by no means peculiar to modern agriculture. Farmers are generally, familiar with chemical pesticides because of their quick, effective actions. However, chemical control poses risks to human lives and environments hence, the necessity of changing to biological control (Ladoye, 1993). The use of chemical pesticides increases the cost of production and also makes the products more expensive (FAO, 2012; Salami and Osonubi, 1999). Another remarkable feature of chemical pesticides is the capacity of the pests and disease species to quickly evolve genetic resistance to the plethora of chemical agents used against them (Dean, 1991; Salami, 1999, Salami, 2009). Soil erosion and underground water contamination have been known to be caused by pesticide residues and fertilizer runoffs (Salami and Osonubi, 2006). As environmental and health hazards mount as a result of heavy pesticide usage, a new holistic perspective emerged in food production-sustainable agriculture. This is a dynamically evolving system in which widely divergent agricultural practices and conditions are evaluated, modified and verified in order to create a productive and continuing sustainable agriculture (Salami *et al.*, 2003; 2005a; 2005b). This concept is the biological or better still crop protection. It is environmentally oriented, easy to use and affordable (Salami, 2004; Awotoye *et al.*, 2009; Adewole *et al.*, 2010).

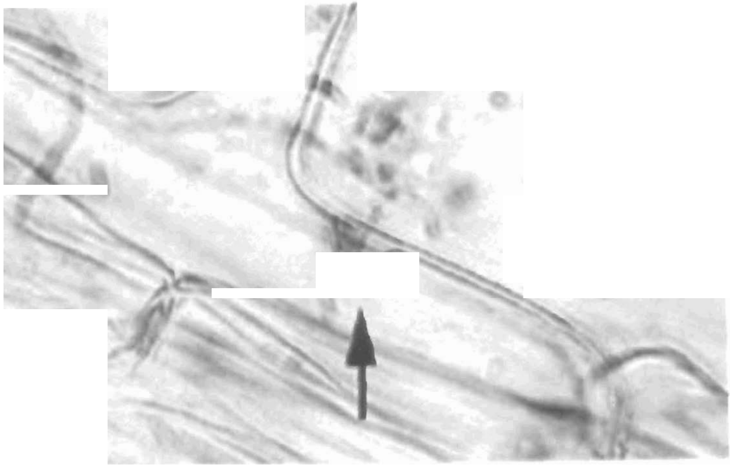


Plate 12: Papilla (arrow) formed around fungal hypha at the site of attempted infection Lignitubers

## PLANT TISSUES AND SPECIALIZED APPENDAGES

Also, part of my research interest focuses on the biotechnology of bio-control in the area of plant-microbe interactions. This is revealing the **enzymatic activities of these interactions and the microbial control in plant diseases and their management** (Ladoye, 1993; Odebode *et al.*, 1995; 1997; Salami *et al.*, 2003).

Many plants and seeds contain proteins that specifically inhibit pathogen and pest's enzymes by forming complexes that block active sites or alter enzyme conformations, ultimately reducing enzyme function

(Salami, 2007; Salami and Akintokun, 2008; 2010). These proteins are generally small and rich in the amino acid cysteine. They include defensins, amylase inhibitors, lectins, and proteinase inhibitors. Unlike simple chemicals such as terpenoids, phenolics, alkaloids, and proteins require a great deal of plant resources and energy to produce; consequently, many defensive proteins are only made in significant quantities after a pathogen or pest has attacked the plant (Salami, 2004; 2008; Bamigboye and Salami, 2010). Once activated, however, defensive proteins and enzymes effectively inhibit fungi, bacteria and nematodes. Hydrolytic enzymes are produced by some plants in response to pathogens and often accumulate in extracellular spaces where they degrade the cell walls of pathogenic fungi (Odebode *et al*, 2001; Salami and Akintokun, 2008; Bamigboye and Salami, 2011). Chitinases are enzymes that catalyze the degradation of chitin, a polymer with a backbone similar to cellulose that is present in the cell walls of true fungi. Glucanases are enzymes that catalyze the degradation of glycosidic linkages in glucans, a class of polymers similar to cellulose that is present in the cell walls of many oomycetes (water molds). Through in-vitro analysis, the anti-fungal properties of these compounds have been verified, and transgenic plants expressing high levels of these enzymes exhibit increased resistance to a wide range of both foliar and root pathogens (Salami, 1999; 2017). Lysozymes are hydrolytic enzymes that are capable of degrading bacterial cell walls.

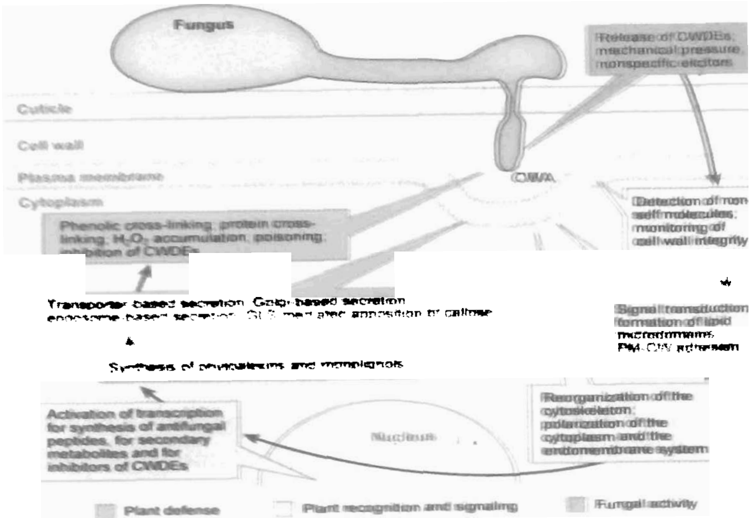



Plate 13: Active defenses at the cell membrane and cell wall

## ADDITIONAL PLANT DEFENSES

The mechanisms discussed in this lecture represent a broad overview of plant defense responses. However, other aspects of plant defense mechanisms include symbiotic relationships, the importance of beneficial microbes on plant health, and the impact of environmental conditions on plant disease. Also, human beings influence disease resistance such as integrated pest management strategies, biological control, cultural practices, and genetic engineering.

## SYNTHESIS OF MY CONTRIBUTION

Mr. Vice-Chancellor, Sir, Ladies and gentlemen, I wish to sum all my research endeavours into four main areas:

(a) Bio-control of pathogens using mycorrhiza and other antagonists: The interactions between mycorrhiza and other organisms their effects on plant growth and yield have been intensely studied. Examples are the reports on the interactions between *Glomus etunicatum* (mycorrhiza), *Phytophthora infestans* (pathogen), and *Trichoderma viride* (a soil-borne fungal antagonist) on pepper seedlings (Salami, 2000; Salami *et al.*, 2001; Salami, 2002). This interaction was found beneficial to the plant in moderating the severity of disease incited on it by *Phytophthora infestans* (Odebode and Salami, 2004). However, the effect of *Trichoderma viride* on the pathogen attested to effective biological control of this pathogen. I have studied the enzymatic mechanisms involved in the ability of mycorrhiza and *Trichoderma* species in suppressing the pathogenicity of disease-causing agents on plants, in order to reduce food insecurity (Odebode *et al.*, 2001). The study revealed the production of cell-wall degrading enzymes in *Glomus etunicatum* (mycorrhiza) association with pepper plant. It confirmed the involvement of these enzymes as infectivity factors in the establishment of the association formed. It also further proved the production of cell wall degrading enzymes by *G. etunicatum* through the reduction in plant growth and attainment of chlorotic symptoms at the early stage of mycorrhizal infection, a physiological effect that disappeared as soon as the mycorrhiza established itself in the inoculated plant. The results showed that arbuscular mycorrhiza (AM) aids maintenance and improvement of soil structure, the uptake of relatively immobile elements; both macronutrients (phosphorus) and micronutrients (zinc), the alleviation of the toxicity of some elements, the interactions with other beneficial soil organisms (nitrogen-fixing rhizobia), and improved protection against pathogens (Bamigboye and Salami, 2010). My research has shown that mycorrhizal associations enable better use of sparingly soluble phosphorus pools (Salami, 2007).

(b) Mycorrhiza agro-biotechnology –Land use improver: Traditional land use involves the practice of shifting cultivation and low input of fertilizer in agriculture in the sub-Saharan region of the tropics. These practices are no longer feasible in Nigeria, due to the high cost and scarcity of supply of the fertilizers as well as the fallow periods that have been drastically reduced. Major factors that constrain tropical soil fertility and sustainable agriculture are low nutrient capital, moisture stress, erosion, high P fixation, high acidity with aluminium toxicity, and low soil biodiversity (Salami and Osonubi, 2002; Bamigboye and Salami 2011). The fragility of many tropical soils limits food production in annual cropping systems. Because some tropical soils under natural conditions have high biological activity. Increased use of the biological potential of these soils through the inoculation of mycorrhiza to counter the challenges of food production problems has been proposed in my studies. My research efforts have provided evidence that careful fertilizer use, proper residue or tree pruning management with vesicular arbuscular mycorrhizal (VAM) inoculation management can ensure stable and high crop yields in the tropical soils (Salami and Osunubi, 2002; Salami *et al*., 2005). This strategy is to develop soil improvement generated by trees (particularly leguminous trees) and cropping system together. This is assisted by microbiological resource (VAM) which can be supplemented with chemicals like fertilizers and biocides when available. The underlying principles is that the quality and quantity of the soil organic matter from the land systems will allow appropriate refinements of the traditional and improved systems to ensure sustainability of the system (Salami *et al*., 2001; Salami, 2002, 2007).

(c) Community Engagement with Resource Poor Farmers: The results of my research have been made available to the local farmers through community engagement in Nigeria and East Africa. In Nigeria, peasant farmers in some villages (Ajibode, Ilupeju, Elewonta, Akeredolu, Erefe, Iyanfoworogi, Kelebe, Kurundun, and Ojo) were trained on alley farming/agro-forestry system which they eventually embraced as well as how to propagate mycorrhizal inoculum on their farms and apply same using locally adapted methods (Salami and Osonubi, 1999, 2002; Salami *et al.,* 2016). This engagement with the farmers was conducted for a period of 3 years and resulted in improved crop yield and income for these resource poor famers. The success of these community engagements has also been replicated in Uganda, East Africa with great success.

Plate 14: Community engagement with the farmers.

Farmers were well educated on the mulching process, that is, when to mulch and how, as well as the type of leguminous shrubs or tree to be used. It was also made known to farmers that instead of fallowing a degraded soil, soybean or legume with VAM inoculation can be used for the improvement of the soil. This will undoubtedly bring in some returns, where farmers use mulching materials for better crop yield. Nigerian farmers were encouraged in the course of our engagement with them, to harness their energy positively towards the appropriate blending of modernity with traditionalism by acquiring professional empowerment through emergence of mycorrhizal biotechnology that will improve the traditional land-use system. It is important to emphasize that since the introduction VAM technology into farmer's farms in our experiments, no farm has been left fallow and the crop yield has increased with every year of cultivation, thereby, confirming the biotechnology as sustainable.

(d) Mushroom Cultivation: I have developed protocols for the cultivation of different species of oyster mushroom e.g. *Pleurotus pulmonarius* (White Mushroom), *P. sajor-caju* and *P. florida* which is an edible mushroom in the Department of Crop Production and Protection for people's consumption. This commenced in 2009 and many graduate students have been trained in my laboratory on mushroom production since then (Bankole, 2012, 2017; Salami *et al.,* 2016; Andrew, 2017; Salami *et al.,* 2017; Bankole and Salami, 2017). This cultivation has also been taken further for use in the area of bioremediation of polluted soils (crude oil and spent engine oil soil) (Salami and Elum, 2010). In my recent and ongoing work, I have found that *P. pulmonarius* is a potential bioremediating agent in sites filled with organopollutants like crude oil. From mushroom cultivation, spent sawdust used as substrate is being recycled into useful Spent Mushroom Compost (SMC) and an agricultural amendment (Edih, 2016). The work demonstrated on a small scale, that the mycelium and spent mushroom compost of *Pleurotus pulmonarius* are useful tools for bioremediation of crude oil polluted soil. It was also discovered that a crude oil polluted soil undergoing bioremediation can be bio-stimulated with mycorrhiza in order to enhance high crop productivity. However, more work is still going on in this area especially as it relates to in-situ application and long term studies of the associated crops and soil type.

## NATIONAL AND INTERNATIONAL RECOGNITION

Mr. Vice Chancellor Sir, as a mark of scholarship and in recognition of my contribution, I have won several international awards and fellowships. These include: Fellow, International Women Forum for Leadership Foundation (IWF) (2014-2015); African Women in Agricultural Research and Development (AWARD) (2013-2014); International Visiting Scholar, United States Department of Agriculture (USDA), Sydney, USA

(2012); NFP/NUFFIC Fellowships, The Netherlands (2012 and 2009); Winner, Women in Science Competition (2009); MASHAV Fellowship, Israel (2009); UNESCO/People's Republic of China Co-Sponsored Fellowship (2006); Fellow, Leadership for Environment and Development (LEAD) International Inc. USA (2002); and LEAD Fellowship Award, 1999 among others.


Plate 15: AWARD Mentoring

Plate 16: Winners of African Women in Science Competition

Plate 17: International Women Leadership Forum

Plate 18: Harvard Business School

Plate 19: Biotechnological training in Israel

Plate 20: International Visiting Scholar, United States Department of Agriculture

I have also been engaged in a series of activities to transfer knowledge to farmers through community engagement programme, as well as to my mentees (mainly my Master and doctoral supervisees) as a form of entrepreneurial programme and skill acquisition. As an accomplished scientist, a budding administrator and a consultant to several organizations within and outside Nigeria, I have enhanced the image of this institution. I have also served as a member of the Planning and Implementation Committee (PIC) of the curriculum for the establishment of several Universities in Nigeria, including Caleb University; Chrisland University; and the proposed EKUMEDHS

My future research interest is in the area of soil health (increasing and sustaining the productivity of land) in order to enhance food security. And definitely, food security will enhance national security and poverty alleviation.

## SUMMARY AND RECOMMENDATIONS

Mr. Vice chancellor Sir, I started my journey as mentioned earlier from the Botany and Microbiology Departments, but today I have been able to apply the knowledge of this field in Agriculture. Hence, I stand on this podium today as a Professor in the Faculty of Agriculture. My methodologies have been based on the biotechnological use of mycorrhiza in improving growth and yield of crop and remediating the polluted environment. I have been able to build an interdisciplinary synergy between different fields of specialization such as Botany, Microbiology, Biochemistry, Ecology and Agriculture.

Micro-organisms affect every aspect of life on Earth but most importantly, they could resolve the problem of hunger if properly harnessed. Some microbes cause disease but many of them are completely harmless. These minute life forms are essential to the cycling of nutrients in the eco-systems of the planet. The use of agro-wastes for the cultivation of mushroom as discovered in my study is what is worth harnessing with all energy. This is because these agro-wastes are ordinary wastes that are becoming a menace to the society such as corncobs, spadix, sawdust, sugarcane bagasse, rice bran, maize straw, groundnut shell, paper wastes, banana leaves, and tiger nuts. These have been biotechnologically converted to substrates for the cultivation of edible mushroom.

Also, worthy of note is the mycorrhizal biotechnology that could improve agricultural production in intensive agricultural practice. This technology have been discovered to be drought tolerant, thereby improving the water holding capacity of the soil, increase the nutrient uptake processes in plant and building formidable wall around the plant for protection against pathogens. All these lead to improved growth and crop yield as well as edibility and palatability. This is critical for increased and continuous supply of food and also, a form of rescue from the rampaging hunger in our society.

Given that there is no equivocation about the beneficial effect of VAM, which are naturally available in Nigeria, there is need for the Nigerian government to promote (for the benefits of smallholder farmers), the use of VAM as an inoculant and as a component of an integrated strategy for the management of the fragile Nigerian agricultural soils. Adoption of this as a technology package will reduce the use of inorganic fertilizers and chemicals inputs for pest and disease control.

Institutions like ADPs and NAERLS should be encouraged to promote large-scale adoption of mycorrhizal inoculum. Awareness on the beneficial effects of this technology for land-use, plant health and productivity enhancement should be promoted. Obafemi Awolowo University may wish to consider the establishment of a National Mycological Centre with the major task of identifying and promoting the use of beneficial fungi species with emphasis on those related to production of food against rampage of hunger.

Mr. Vice- Chancellor Sir, I wish to allude to the saying that in the modern world, no nation can truly be great if it cannot feed her populace and no meaningful progress can be made in other sectors of life if there is hunger on rampage! To avoid this, we must move away from the old order and admit that the cheese has refused to be stagnant by moving away from the traditional stations. The traditional practice of agriculture solely based on the use of hazardous chemical fertilizer should give way to the use of soil micro-organism like the arbuscular mycorrhizal fungi (AMF) to improve plant growth in a symbiotic association formed between plants and the soil fungi. The cheese has also moved to the order of befriending the basidiomycetes in the name 'MUSHROOM' placing food directly on the dining table both in cash and kind, serving as good source of revenue to tame the rampage from hunger!

## CONCLUDING REMARKS

Mr. Vice Chancellor Sir, and my distinguished audience, all these research works have not been my solo efforts, but joint efforts with my colleagues, mentors and mentees. I will at this juncture give credence to my teachers and mentors right from the lower level i.e. primary (as I first mentioned) to the postgraduate levels. I also want to appreciate my parents, Daddy and Mummy Ladoye (seated here today), who funded me at all levels of education not minding my being a girl child; Daddy and Mummy, you remain the best!

Most importantly and worthy of note is 'my God given vessel of encouragement'; Professor Ayobami Salami, the unbeatable MINE; ever resilient and solid like rock of Gibraltar, articulate and caring MINE; my only MINE who will not relent or despair in following and supporting me to any level in my academic pursuit. Ladies and gentlemen, let me share a secret with you. Today makes it **EXACTLTY** 25 years ago that I walked to the altar as an innocent young girl to say "I do"; with MINE fixing the ring on my fourth finger. It has been a quarter of a century, laden with GRACE, which is evident, even for the blind to see and a *Thomas* to believe! You have infected me with your unquenchable optimism and irrepressible spirit, extraordinary passion for scholarship and unparalleled commitment to selfless service. You have always seen rainbow where other people saw cloud, and today is an eloquent testimony of the wisdom of being joined to the same garment of destiny with a man, supernaturally endowed with grace, vision and passion. Thank you so very much my love, for making me your life DEAREST while you remain MINE for life. I hereby dedicate today to God and our Union.

I appreciate you and all our children, Ayobami Timothy, Ayomide Oluwatooni and Ayomipo Oluwatamilore for your wonderful and unflinching support and encouragement as well as immense sacrifice you have all had to make, in order for me to qualify to stand on this podium today. I want to also thank all my siblings and friends (both old and new). I have also been blessed with wonderful graduate students and colleagues in my Department and even this wonderful august audience, I appreciate you all. Above all, I want to publicly acknowledge that I owe it all to God, He granted me grace, wisdom, knowledge and understanding. He is the immortal, invisible, ancient of days, my shield, and buckler, my glory, my rock, my strong tower, my help, my sustainer, the lifter of my head, the most high and my almighty! '*Olorun, to da awon oke igba a ni, Eyin ni mo fi ope e mi fun…*'. Thank you all for your attention.

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