THE FEDERAL UNIVERSITY OF TECHNOLOGY AKURE, NIGERIA

PRODUCTIVITY OF UNSEEN ALLIES IN CONDUCIVE AND UNCONDUCIVE ENVIRONMENTS: A GREAT WONDER

INAUGURAL LECTURE SERIES 200

Delivered by

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PROFESSOR OF APPLIED SOIL AND ENVIRONMENTAL MICROBIOLOGY

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PROTOCOL

The Vice Chancellor,
Deputy Vice Chancellor (Academic),
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Fellow Professors and Academic Colleagues,
Members of Administrative and Technical Staff,
Distinguished Guests and Friends of the University,
Ladies and Gentlemen of the Press,
Distinguished Ladies and Gentlemen,
Great FUTARIANS.

1.0 INTRODUCTION

The conferral of a professorial chair at any University carries with it a solemn obligation: the inaugural lecture, the academic rite of passage in which elevated scholar accounts to the university community — and to the broader public — for the intellectual labour that justified the appointment. It is the moment at which a scholar's journal articles, conference papers, and laboratory notebooks are gathered into a coherent, accessible narrative; at which the arc of a research life is made visible; and at which a commitment to the future is publicly proclaimed. This lecture fulfils that obligation.

1.1 Preamble

Madam Vice Chancellor, Ma, my plan for this "Conducive inaugural lecture" started when some people in my community asked, "When will you present your inaugural lecture?". I replied that I would do it whenever it is conducive for me as it is done normally. They questioned further, "How can that be?" When I realized that the

understanding of some people in the public shows that nobody becomes a professor without induction or inauguration, I started having unconducive feelings without presenting inaugural lecture like "unseen ally in conducive and unconducive environments. It is a singular privilege to stand before this distinguished assembly today. Like the unseen allies whose productivity this lecture celebrates, the scholar's work proceeds often in silence — in laboratories and libraries, in field sites, research stations and laboratories — until the moment arrives when that work must be made visible and accountable to the broader community. That moment is now. Ladies and gentlemen, I have come this day to present this inaugural lecture titled **"Productivity of unseen allies in conducive and unconducive environments: A Great Wonder!** I am privileged to present to you the 200th Inaugural lecture of this ivory tower, The Federal University of Technology, Akure (FUTA). One of my academic mentors in the Department of Microbiology, Prof. F. A. Akinyosoye delivered the 1st inaugural lecture titled "Microbial Biotechnology: A tool for Global Economic Development" on 25th September 2007. The 2nd was delivered by Professor A. K. Onifade on 16th February 2010 with the title: "Phytotherapy: A Random Walk through a Random Forest". This was followed by Professor T. T. Adebolu with the title: "Mechanism of Adaptive Immunity and the endless Battle against Darrhoaegenic Bacteria on 11th July, 2017 while the 4th was by Professor M. K. Oladunmoye with the title: "Natural Product Derived Antimicrobials: The Myth and Reality" on March 13, 2018. The 5th inaugural lecture in the Department was delivered by Professor V. O. Oyetayo on 14th January 2020 with the title "Health Promotion: The Probiotic and Myconutraceutical Approach. This was followed by Professor B. J. Akinyele on February 11, 2020 with the title "Fungi and Fungal Products: Integral part of Industrialization in a Developing Economy. The 7th inaugural lecture was delivered by

Professor E. O. Dada on October 5, 2021 with the title: "Tropical Countries: A Haven of Human Parasite: Nigeria a Case Study". This is the 8th Inaugural Lecture from the Department of Microbiology, FUTA, the 1st from Environmental Microbiology Unit in the Department.

Madam Vice Chancellor, my journey as a microbiologist started in 1990 when I was admitted as an undergraduate student into the Department of Botany and Microbiology, of the prestigious and premier University, University of Ibadan (Recte Sapere Fons). I graduated with B. Sc. degree in 1995. In 1997, I was admitted into the same Department for my M. Sc. degree and I graduated in 1998. After that, I was employed as an Assistant Lecturer into the Department of Biology in 2000, Federal University of Technology, Akure. While working as a lecturer, I was on my Ph. D programme which was completed in December 2009. By the grace of God, I rose through the ranks from Assistant Lecturer to a Professor on 1st October 2017.

1.2 Genesis about Creation of Environment, A Great Wonder

"In the beginning God created the heaven and the earth. And the earth was without form, and void, and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters" (Genesis 1:1,2). One of the Environmental Microbiology courses I teach is Aquatic Microbiology, an environment where the spirit of God started moving. "And God said let there be a firmament in the midst of the waters, let it divide the waters from the waters. And God made the firmament, and divided the waters which were under the firmament. From the waters which were above the firmament: and it was so. And God said, let the waters under the heaven be gathered together unto one place, and let the dry land

appear: and it was so (Genesis 1: 6, 7, 9). Soil was another environment God created next to water and I teach Soil Microbiology. Although a Professor of Microbiology, I am still a student learning under God Almighty, the Greatest Teacher. "And God called the dry land Earth and the gathering together of the waters called the seas and God saw that it was good" (Genesis 1: 10).

A great miracle happened from soil and water environments when Jesus was on the earth. "And as Jesus passed by, he saw a man which was blind from his birth. And his disciples asked him, saying Master, who did sin, this man, or his parents, that he was born blind? Jesus answered, neither hath this man sinned nor his parents: but that the works of God should be made manifest in him. When he has thus spoken, he spat (water) on the ground, and made clay of the spittle, and he anointed the eyes of the blind man with the clay (soil) and said unto him go, wash in the pool (water of Siloam (which is by interpretation, Sent). He went his way therefore and washed and come seeing (John 9: 1-3, 6,7). What a great wonder! Today, we have learned that there are antibiotic-producing microorganisms from soil and water environments. Glory be to God.

1.3 Microbiology and Microorganisms

Microbiology is the scientific discipline that studies the biology and ecology of microscopic or submicroscopic organisms normally invisible to the naked eye. It encompasses the investigation of changes that such organisms bring about in other organisms and in non-living matter. Some branches of microbiology include air, soil, aquatic, petroleum, medical and food microbiology. Microorganisms are very minute in size and constitute the vast and diverse microbial world which occupies virtually every niche and habitat on Earth, from the deepest depths of the ocean to the highest

mountain peaks, living in the air, water and soil in our environments, on and in the food we eat, on and within our bodies. Nominal cell counts of $\geq 10^5$ cells per ml in surface sea water predict that the oceans harbour 3.6×10^{26} microbial cells. Communities of bacteria, archaea, microalgae, protozoans and microfungi account for most of the oceanic biomass. A gram of soil contains $\geq 10^6$ cells.

1.4 Discovery of the microscope

Robert Hooke (1635 – 1703) made and used a compound microscope in the 1660s and described his microscopic creatures in his classic "Micrographia" (1665). Although Hooke's highest magnifications were possibly enough to reveal bacteria, he apparently could not see them probably because he studied mainly opaque objects in the dry state by reflected light, conditions that are not optimal for observing bacteria.

The exact beginning of the knowledge about the existence of microorganisms can be traced back only to the latter part of the seventeenth century when Antony Van Leeuwenhoek (1677) first recorded observations of microorganisms (bacteria, yeasts and protozoa) seen in water, faeces and tooth scrapings under his own microscopes which were not compound. Leeuwenhoek (1632-1723), basically a cloth maker and tailor by trade, was also a surveyor and the official wine taster of Delft, Holland and his basic interest in microscopes was probably related to the use of magnifying glasses to examine fabrics. He transmitted his findings in a series of more than two hundred letters to the Royal Society of London during his lifetime. He described such tiny creatures as "dierkens" or "animalcula viva" which were translated in English as "animalcules" by the Royal Society. Leeuwenhoek was later elected fellow of the Royal Society.

Although there are reports of works on microorganisms, O. F. Muller gave first classification of bacterial microbes in 1773 and 1788 and coined the terms “vibrio” and “Monas” for certain forms. Ehrenberg established a new genus “Bacterium” in 1829. Leeuwenhoek’s animalcules took two centuries to cause any spurt among scientists when their importance was realised in different areas of human affairs.

2.0 GENERAL OVERVIEW OF ENVIRONMENTAL MICROBIOLOGY

Environmental Microbiology encompasses the study of microorganisms associated with soil, water and air environments.

2.1 Soil Microbiology

Soil microbiology is the study of microorganisms that live in the soil. The main thrust is on their metabolic activities and their roles in the energy flow and cycling of nutrients associated with primary productivity.

Soil is the upper layer of most of the earth surface and varies in depth from inches to over twenty feet. It is a product of weathered rock but quite distinct in its characteristic. Soil is not a single unit because there are different kinds of soils. The type of soil which develops from the underlying rock, is as a result of interaction of four factors: the parent material (rock), climate, age (time or period) and biological factors.

2.1.1 Soil/Rhizosphere microorganisms

It seems obvious that microorganisms are in the soil because there is food or nutrient. Soils are excellent cultural media for the growth of many types of microorganisms which include bacteria, fungi, algae, protozoa and viruses. A spoonful of soil contains billions of microorganisms. In general, microbial population is found in the

upper six to twelve inches (15 to 30cm) of soil and the number decreases with depth.

The unique soil environment under the influence of plant roots is called rhizosphere (Plate 1). The width of the zone of soil varies with the type and age of the plant and soil environmental conditions. Roots stimulate various types of microorganisms by "rhizosphere effect" which results in higher microbial complex than that of root free soil. Higher number of bacteria, actinomycetes and fungi occur in rhizosphere soil but fungi are least affected. One of the most characteristic rhizosphere effect is the preferential stimulation of bacteria requiring amino acids for maximum growth. The bacteria responding to the presence of roots are short Gram negative rods which invariably make up a larger percentage of rhizosphere than normal soil flora. The percentage incidence of short Gram-positive rods (i.e. coccoid rods and spore-forming bacteria, such as *Bacillus* species) declines around the rhizosphere. Microorganisms in the rhizosphere may exert profound influence upon plant itself by decomposition of organic matter, affecting uptake of nutrients by plants, associative and antagonistic relationships and actual parasitism of plants.

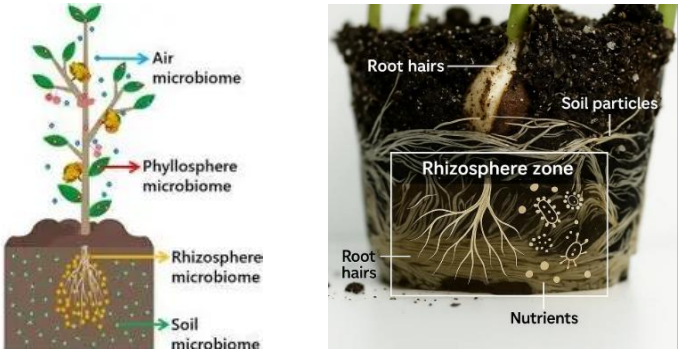


Plate 1: The Rhizosphere

Functions of microorganisms in the soil

Maximum microbial growth and activity in the soil is found around the roots of plants called the rhizosphere. Practically, all ecological interactions such as symbiosis, syntrophism, synergism, commensalism and antagonism exist between plants and microorganisms. Some of these interactions found in this region are favourable and indispensable while some are unfavourable and lethal. The most important function of soil microorganisms is to decompose various kinds of organic matters.

Bacteria

Many types of bacteria are found in the soil. Out of them, some are autotrophic and utilise inorganic compounds for their energy and growth. The majority of bacteria are heterotrophic and utilise large amounts of organic matter. These belong to the order Eubacteriales and Actinomycetales. The latter group is most frequently represented by organisms of the genera *Streptomyces* (Plate 2), *Nocardia* and *Micromonospora*. These have an earthy odour and are responsible for the much of the smell of a freshly plowed field.

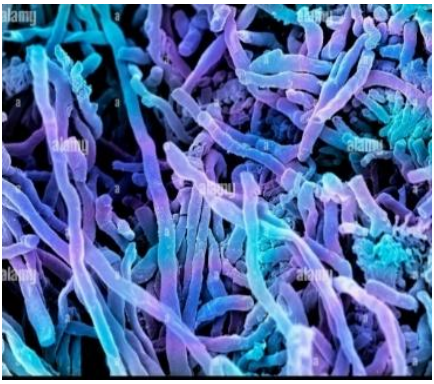


Plate 2: *Streptomyces* species

Fungi

These include a group of organisms from the moulds to the large fleshy fungi such as mushrooms (Plate 3). The development of fungi is especially favoured by soils having an acidic reaction and where an aerobic condition is likely to be present near the surface. Since they exist in both the mycelial and spore stages, it is difficult to estimate their numbers. Their numbers range from thousands to hundred of thousands. Fungi are active in decomposition of cellulose and lignin of plant tissue.

Plate 3: Mushroom (Source: Wikipedia.com)

2.1.2 Some factors that determine the presence of microorganisms in the soil

The number and kinds of organisms found in soil depend upon the nature of soil, depth, season of the year and state of cultivation, soil reactions, organic matter, temperature, moisture, aeration and other environmental conditions.

i. **Soil Atmosphere:** Microorganisms can grow under aerobic (e. g. *Bacillus* species) and anaerobic (e. g. *Clostridium* species) environments.

ii. **Soil Water:** Fungi are generally more tolerant of higher water potentials (greater water stress) than bacteria. The nitrifiers as typified by *Nitrosomonas* are less tolerant of stress than ammonifiers as typified by *Clostridium* and *Penicillium.*

iii. **Soil Temperature:** Temperature affects both the physiological reaction rates of cells and the physicochemical characteristics of the environment. The specific proteins such as those of flagella, ribosomes of thermophilic bacteria are more heat stable than those of mesophilic bacteria. At low temperature, all proteins undergo slight conformational changes attributable to the weakening of the bonds that control tertiary structure. Some psychrophilic bacteria are capable of growth below the freezing point providing the osmotic concentration of the ambient solution or of the organism's cytoplasmic constituents is sufficiently high to permit the cell interiors to remain unfrozen.

2.2 Aquatic Microbiology:

Aquatic microbiology is the study of microorganisms and their activities in natural waters such as fresh waters, estuaries, and marine waters. Natural waters include springs, lakes, rivers, bays and seas. Microorganisms that inhabit natural waters include viruses, bacteria, algae, protozoa and microscopic fungi. Natural waters include atmospheric, surface ground and stored waters.

2.2.2 Some factors that affect the presence of microorganisms in water

Some factors that affect the presence of microorganisms in water are as follows

i. **Temperature:** The temperature of surface water varies from near 0^{o}C in polar regions to 30- 40^{o}C in equatorial regions. More than 90% of the marine environment is below 5^{o}C which

is favourable for the growth of psychrophilic organisms. Microorganisms do occur in natural hot springs where temperature is as high as 70 – 80°C. *Thermus aquaticus* has an optimum growth temperature of 70 – 72°C. Thermophilic microorganisms capable of growing at 250°C and 265 atmospheric pressure in geothermal vents of Pacific Ocean floor have been discovered.

ii. **Hydrostatic Pressure:** Hydrostatic pressure affects chemical equilibrium which in turn results in lowering the pH of seawater. It thereby results in a change in the solubility of nutrients such as bicarbonate etc. It also results to increase in the boiling point of water thereby maintaining water in its liquid state as high temperature and pressure. By definition, hydrostatic pressure increases with depth at the rate of 1 atmosphere per 10 metres. Barophilic microorganisms have been isolated from pacific trenches (depth 1,000 to 10,000m) where enormous hydrostatic pressures exist (› 100 atmospheres).

iii. **Light:** Primary producers in most aquatic habitats are algae, and their growth is restricted to the upper layers of water where there is light.

iv. **Salinity:** The degree of salinity in natural waters ranges from near zero in freshwater to saturation in lakes. The principal salts are chlorides, sulphates and carbonates of sodium, potassium, calcium and magnesium. Their concentrations are usually less in shallow off-shore regions and near river mouths or boundaries. Most marine microorganisms are halophilic and they grow best at salt concentration of 2.5 to 4.0 percent. Microorganism from freshwaters such as lakes and rivers do not grow at a salt concentration of more than 1%.

2.3 Air Microbiology

Air microbiology is simply the study of microorganisms present in the air inside (indoors) and outside (outdoors) of buildings, from troposphere (near the earth) to atmosphere.

2.3.1 Air environment and microorganisms

Of all environments, air is in many ways the simplest because it consists of a single phase, gas, apart from condensed water vapour and dust. Air is composed, by volume, of approximately 78% nitrogen, 21% oxygen, 0.9% argon, 0.03% CO_2 and traces of other gases and low concentration of organic and inorganic nutrients. Air contains free water at irregular intervals. One of the main problems of any airborne microorganisms is preventing desiccation. The layer of air nearest to the earth, the troposphere extends to about 11km in temperate region and 16km in the tropics. Apart from irregularities near the earth's surface, there is a steady decrease in temperature with light (about 1^{o}C per 150m) until the top of the troposphere when temperature starts to increase.

Many organisms which normally grow exposed to sunlight have pigment such as melanin in their walls and the air itself especially the ozone layer absorbs UV light so that the lower the microorganisms in the atmosphere the less the UV exposure. Microorganisms usually occur in air in small numbers compared with soil or water. They are rarely metabolically active because of low water and nutrient levels. Air is mainly important as a transport and dispersal for microorganisms.

Most microorganisms have no special mechanisms enabling them to become airborne. Soil microbes may be blown on dust, sea spray contain organisms from plankton and neuston. Many man's activities accentuate the passive methods of becoming airborne by creating turbulence and disturbing soil vegetation. Rain creates

aerosol on impact as the droplet can contain microbes from the surface from the air through which the rain passed. Bacteria which are sheltered in a soil particle may survive much longer than individual cells exposed to UV and dry air. Aerosol droplets dry up very rapidly and the resulting particles (nuclei) may again protect any organism.

2.3.3 Factors affecting the presence of microorganisms in the atmosphere

Factors affecting the presence of microorganisms in the atmosphere include the following: number and kind of spores, wind currents, formation of aerosols or droplets (created by rain), passive mechanisms (such as coughing, sneezing by humans and animals), active mechanisms (e. g. release of spores by fungi), desiccation, exposure to radiation and formation of pigments. Some microorganisms are protected from these lethal effects by pigments. Pigmented fungi and bacteria suffer less damage when exposed to UV light than colourless species. Exposure to sunlight in the air is lethal to non-pigmented strains of *Micrococcus luteus* but not to yellow pigmented strains. Death does not occur in the absence of air indicating that light-induced killing is a photooxidation process that requires oxygen. Similarly, a colourless (Carotenoid-free) mutant of *Halobacterium salinarium* can be inhibited by high light intensities whereas the pigmented wild-type strain was not inhibited.

3.0. SPECIFIC ROLES OF SOME MICROORGANISMS IN THEIR ENVIRONMENTS

3.1 Biodegradation and Bioremediation

Biodegradation can be defined as the decomposition of a substance through the action of biological agents, especially microorganisms. In general, biodegradation is the process of decay initiated by microorganisms. In a stricter sense, however, biodegradation has

come to signify the complete microbial breakdown or mineralization of complex materials into simple inorganic constituents such as carbon dioxide, water and mineral components. It also results in the removal of certain man-made substance such as pesticide or biocides from the soil environment and reduction in their toxicity. The biodegradability of a substance. that is, its susceptibility to decomposition by natural biological processes has become a criterion by which the worthiness of a commercial product is evaluated.

Bioremediation is an environmental clean-up technique that uses microorganisms (bacteria, fungi) and plants to degrade, transform, or detoxify hazardous pollutants- such as oil spills, heavy metals and industrial waste- into non-toxic or less harmful substances. It leverages natural biological processes to restore contaminated soil and water.

3.1.1 Pesticides and soil microorganisms.

Microflora alters a multitude of chemicals i. e. pesticides to which they are exposed by converting them to products that suppress the same kind of organisms as the substrate compound. Chemicals applied directly to seeds sometimes affect nodule bacteria to such an extent that the nodules fail to appear and hence nitrogen is not available to the legumes. Many genera of heterotrophs use pesticides as substrates either as cometabolising molecule or using them as nutrients.

3.1.2 Petroleum degradation by soil microorganisms

Petroleum degradation by soil microorganisms is a natural bioremediation process where bacteria, fungi, and yeast utilise hydrocarbons as carbon and energy sources, transforming toxic oil pollutant into harmless substances like CO_2 and water. Bacteria such as *Pseudomonas*, *Bacillus*, *Rhodococcus*, and *Mycobacterium* use

enzymes to breakdown complex compounds. Microorganisms produce degrading enzymes and often create biosurfactants to increase the bioavailability of hydrophobic hydrocarbons. Mixed cultures (Consortia) are often more effective than single strains because different species degrade different components of crude oil, leading to higher efficiency.

3.1.3 Production of cooking gas (methane) from waste materials

Methane is a clean burning odourless gas with a high heating value. It can be used for cooking, heating, and running internal combustion engines. Methane gas is produced from organic waste materials such as agricultural residue, kitchen waste, animal manure and sewage - through a process called anaerobic digestion. Biomass that is high in moisture content such as sewage sludge, and food processing waste is suitable for producing biogas (containing high percentage of methane). Methane is formed by methanogenic bacteria (such as *Methanobacterium, Methanobacillus and Methanococcus*) as the last product of a complex series of reactions involving a number of different organisms. Microorganisms breakdown wastes in sealed, oxygen-free tanks (biodigesters), producing up to 50 to 70% methane. The resulting biogas acts as renewable fuel for heating or electricity, while the remaining digestate is used as nutrient-rich fertiliser.

3.2. Biopesticides and control of plant diseases.

Biopesticides are sustainable, natural agents derived from microorganisms, plants, and minerals used to control plant diseases. They offer eco-friendly alternatives to synthetic chemicals by employing targeted actions such as competition, hyper-parasitism and inducing systemic resistance. Primarily used as preventative tools they are highly effective against soil-borne pathogens. Microbial pesticides utilise microorganisms (bacteria, fungi,

viruses) to fight pathogens. Examples include *Trichoderma* species (fungal antagonist for root rot) and *Bacillus subtilis* (bacterial control for powdery mildew.

3.3 Biofertilizers and Plant Growth:

Biofertilizers (Plate 4) are substances containing living microorganisms such as bacteria, fungi, or algae that, when applied to seeds, plant surfaces, or soil, promote growth by increasing the supply or availability of essential nutrients. They restore natural soil fertility, improve plant health, and provide eco-friendly alternative to chemical fertilizers.

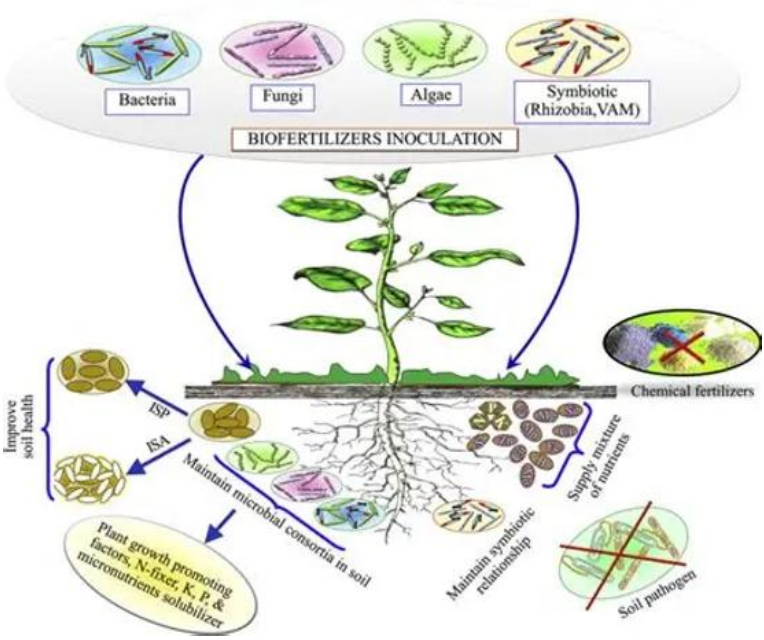


Plate 4: Biofertilizers

Types of Biofertilizers include the following:

i. **Mycorrhizal fungi:** These fungi increase nutrient uptake especially phosphorus by expanding the root system's (Plate 5) reach.

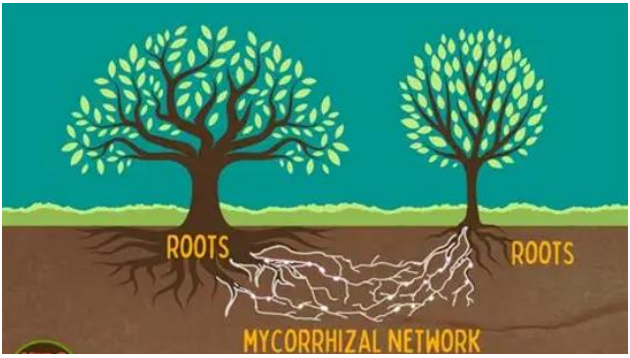


Plate 5: Mycorrhizal network

ii. **Nitrogen-Fixing Biofertilizers:** These convert atmospheric nitrogen into usable ammonia for plants, including *Rhizobium* obtained from root nodules (Plate 6) of legumes and non-symbiotic nitrogen fixers such as *Azospirillum* and *Azotobacter*.

Plate 6: Root nodules of legumes

iii. **Phosphorus-Solubilizing Bacteria:** These are microbes that solubilize insoluble phosphorus in the soil, making it available to plants.

Methods of applying biofertilizers include dipping seedling roots into a suspension of the biofertilizer before transplanting. This is common for rice and vegetables. Other methods of application of biofertilizers is by coating seeds with a mixture of biofertilizer and adhesive before planting, soil application, mixing biofertilizers with compost or soil before applying to fields.

3.4 Biocontrol Agents

Biocontrol agents are living organisms—predators, parasitoids, or pathogens—used to sustainably manage pests, weeds, and plant diseases, acting as eco-friendly alternatives to chemical pesticides.

3.4.1 Biocontrol of human diseases

Biocontrol of human diseases involves using natural enemies (predators, parasites, or pathogens) to suppress organisms that transmit diseases, such as mosquitoes, ticks, and flies. This includes releasing bacteria like *Bacillus thuringiensis* Var. israelensis (Bti) to kill larvae. utilizing *Wolbachia* (a bacterium) to prevent mosquitoes from transmitting viruses like dengue. *Bacillus sphaericus* and Bti are widely used to target mosquito larvae in water sources.

3.4.2 Production of antibiotics from soil microorganisms

Soil microorganisms are the primary source of natural antibiotics, producing these compounds as a defence mechanism against competitors in nutrient-scarce environments. Over 70% of known natural antibiotics, including streptomycin and tetracycline, are derived from Actinomycetes—thread-like bacteria—and other fungi and bacteria found in soil.

3.4.3 Synthesis of nanoparticles by soil microorganisms

Soil microorganisms synthesise nanoparticles - an eco-friendly "green" approach—using bacteria, fungi, and yeasts to convert metal salts into stable metal nanoparticles (e.g., silver, gold, iron oxide). Microbes act as natural nanofactories, using enzymes (like nitrate reductase) to reduce metal ions, producing particles 1-100 nm in size for biomedical and environmental uses. These biogenic nanoparticles are used for: Antibacterial agents Bio-imaging Drug delivery Environmental bioremediation Nanoparticles (NPs) are revolutionising agricultural biocontrol, acting as eco-friendly alternatives to chemical pesticides by offering targeted sustained delivery of active agents to suppress plant diseases and pests. Metallic (Ag, ZnO, CuO) and organic (chitosan) NPs are widely effective in controlling fungi, bacteria, and insects. Silver (Ag) nanoparticles are widely used for their potent antibacterial and antifungal properties potent antibacterial and antifungal properties.

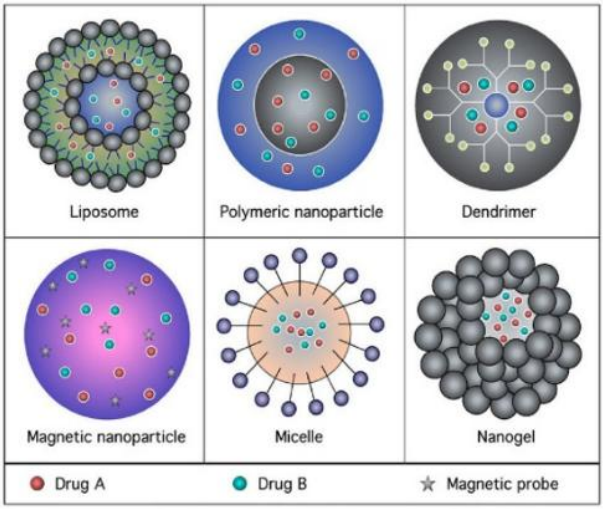


Plate 7 Nanoparticles

3.5 Biosynthesis of Plant Growth Substances and Enzymes by Soil Microorganisms

3.5.1 Production of phytohormones by soil microorganisms

Microorganisms, particularly plant-growth promoting rhizobacteria (PGPR) and fungi, produce phytohormones—including indole-3-acetic acid (IAA/auxin), gibberellins, cytokinins and ethylene—that directly regulate plant development, enhance root growth, and improve stress tolerance. These beneficial microbes, often called probiotics, colonize the rhizosphere and enhance agricultural productivity by modulating hormonal levels and supplying essential nutrients. Indole-3-acetic acid (IAA - Auxin) is the most common phytohormone produced by bacteria, enhancing root system architecture and plant growth. Microbes such as *Pseudomonas*, *Azotobacter*, *Bacillus* and *Azospirillum*, thrive on root exudates and produce these hormones to help plants thrive.

3.5.2 Production of enzymes by soil microorganisms

Soil microorganisms, including bacteria, fungi, actinomycetes, and protozoa, are the primary producers of soil enzymes, essential catalysts that decompose organic matter, recycle nutrients (C, N, P, S) and enhance soil health. These microorganisms release extracellular enzymes (e. g. cellulases, proteases, phosphatases) that catalyse metabolic processes and maintain the ecological balance of the soil ecosystem.

4.0 MODEST CONTRIBUTION TO KNOWLEDGE

Collectively, my research outputs span from 2005 till date and encompass more than sixty peer-reviewed publications. I have supervised more than thirty postgraduate students to completion, and generated findings which have direct policy relevance across agricultural microbiology, environmental regulation, water quality

management, antibiotic stewardship, and industrial biotechnology as stated below:

4.1 Agrochemicals, Soil Microorganisms and Plant Health

Literatures are replete on fungicide efficacy - yield increases, disease suppression rates and crop protection. Howard (1991), Prescott *et al*. (2005) and Funke *et al.* (2005) among others acknowledged in general terms that pesticides could affect non-target soil organisms, but none had examined, within the specific context of Nigerian cowpea cultivation, precisely which beneficial organisms were being inhibited, and at what cost to the functional ecology of the soil.

Cowpea (*Vigna unguiculata* (L.) Walp) is the most economically important food legume in Nigeria, the second most important pulse crop in Africa, a critical source of dietary protein for millions of smallholder farming households, and a species whose symbiotic nitrogen-fixing relationship with *Bradyrhizobium* and related organisms makes it a potential vehicle for reducing fertiliser costs in low-input farming systems (Omokaro & Ajakaiye, 1989). Cowpea is not simply a commercial crop in Nigeria. It is a nutritional lifeline — the primary dietary protein source for smallholder farming communities across the Southwest - and its productivity is inseparable from the microbial communities inhabiting its root zone.

Madam Vice Chancellor, **Ekundayo** and Oladunmoye (2007) examined what happened when *Fusarium oxysporum* and *F. solani* obtained from rhizospheres of cowpea were exposed to different concentrations of benomyl. This study revealed that in the absence of benomyl, both *Fusarium* species produced beauvericin, a cyclic depsipeptide with demonstrable antimicrobial activity against *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Salmonella paratyphi*. In the presence of benomyl at high concentrations, this antimicrobial production was abolished completely. However, at a

sub-inhibitory concentration of 0.002 g/mL, benomyl appeared to genetically modify *Fusarium solani* in a manner that stimulated rather than suppressed antimicrobial activity, enabling the inhibition of *Klebsiella pneumoniae*.

Ekundayo (2010) examined the effects of six concentrations of benomyl (0.00 to 0.80 g/ml) on the rhizosphere and non-rhizosphere bacteria of cowpea (*Vigna unguiculata* IT93K-452-1) and, critically, on the ability of those bacteria to solubilise phosphate. The experiment was conducted in a 2 × 6 factorial completely randomised design with three replications, using 1.5 kg of sterilised top soil per polyethylene pot, with serial harvesting at 5, 10, 15, 20, 25, and 30 days post-planting. The bacterium responsible for nodulation of cowpea was identified as *Bradyrhizobium japonicum.* Rhizosphere isolates included *Bacillus subtilis, Staphylococcus aureus, and Micrococcus luteus*; non-rhizosphere isolates included *Arthrobacter simplex, Azotobacter chroococcum, Pseudomonas aeruginosa,* and *Bacillus subtilis*. Both *Azotobacter chroococcum* and *Pseudomonas aeruginosa* are asymbiotic nitrogen fixers, a finding of considerable agronomic significance. Table 1 presents the core findings of this study. As benomyl concentration increased from 0.00 to 0.80 g/ml, bacterial populations in the rhizosphere decreased from 12.6×10^8 to 9.9×10^8 cfu/g, and nodule counts decreased from 3.1 to 0.5 (a nodule loss of 94.3% at the highest concentration relative to the control). Cowpea seedlings were healthy and showed no appreciable loss of root nodules or beneficial rhizosphere bacteria at 0.10 and 0.20 g/ml of benomyl. These two concentrations define the safe operating window for benomyl application in cowpea cultivation.

Table 1: Influence of benomyl concentration on rhizosphere bacteria and nodule counts in 30-day cowpea seedlings

Benomyl Concentration (g/ml)	Bacteria (cfu × 10^8/g)	Nodule Count	Nodule Loss vs. Control (%)	Interpretation
0.00 (Control)	12.6c	3.1c	—	Full rhizosphere function
0.05	12.2c	3.0c	3.2	Minimal disruption
0.10	12.1c	2.5c	19.4	Within safe operating window
0.20	11.2c	2.4c	22.6	Upper boundary of safe window
0.40	10.4b	1.7b	45.2	Significant disruption begins
0.80	9.9a	0.5a	94.3	Near-total nodule destruction — unsafe

Values followed by different superscripts within the same column are significantly different at $p \leq 0.05$.

Benomyl at 0.80 g/ml enhanced phosphate solubilisation by *Bacillus subtilis* and *Arthrobacter simplex* (both from rhizosphere and non-rhizosphere soils) despite suppressing overall bacterial populations. This organism-specific resilience is explained, at least in part, by the finding that benomyl did not alter the plasmid molecular weight of *Bacillus subtilis* (which remained > 1,100 base pairs), while it reduced the plasmid size in *Arthrobacter simplex* from 1,100 to 100 base pairs. The increase in phosphate solubilisation by *Arthrobacter simplex* may reflect the proposition that physiological or genetic changes induced by benomyl exposure can stimulate metabolic activities related to the biodegradation of xenobiotics and organic

chemicals (Zhang *et al*., 2005). The critical practical recommendation from this subtheme is that *Bacillus subtilis* may be inoculated into the rhizosphere soil of cowpea to augment soluble phosphate availability in benomyl-treated soils.

In another study, **Ekundayo** and Arotupin (2010) evaluated the response of rhizosphere fungi to different doses of benomyl and their ability to synthesize phytases. The results showed benomyl at all concentrations used inhibited the mycelial growth of *Aspergillus fumigatus* and *Rhizopus stolonifer* with inhibition zones of 29.50±0.50 to 50.00±0.00mm and 27.00±0.00 to 46.00±00mm respectively. Also, there was a reduction in amount of phosphorous released by *A. flavus* treated with benomyl compared with the untreated. However, the amount of P released increased considerably in *F. solani* and *R. stolonifer* treated with benomyl. In non-rhizosphere fungi, the amount of P increased in *A. fumigatus* and *R. stolonifer* treated with benomyl while slight decrease in P by *F. solani* treated with benomyl was observed. Therefore, understanding the response of soil fungi to benomyl is of paramount importance as it stimulates P release for plant uptakes in some fungi and inhibitory in others.

In another study, **Ekundayo *et al.* (**2011) evaluated the biological and chemical control of root rot disease of cowpea caused by *Fusarium solani* using *Glomus mosseae* and benomyl respectively. Six concentrations of benomyl: 0.00 (control), 0.05, 0.10, 0.20,0.40 and 0.80g/ml were assayed by using 1.5kg of top soil collected from the nursery of Federal University of Technology, Akure, Ondo State, Nigeria. *Glomus mosseae* and *Fusarium solani* in the *in vitro* study showed that benomyl concentration was directly proportional to *Fusarium* suppression. Also, there was a decrease in root length of cowpea seedlings with increase in the benomyl concentration in

Fusarium inoculated soil. However, the root length of cowpea seedlings was greater in *Glomus mosseae* inoculated soil at benomyl concentrations of 0.05 and 0.20g/ml and in *Glomus/ Fusarium* inoculated soil at benomyl concentrations of 0.05 and 0.80g/ml. The highest spore count (89.0 per100g of soil) of *Glomus mosseae* was recorded in *Glomus* inoculated soil at 0.05g/ml of benomyl and the lowest count (4.7per 100g of soil) was recorded at 0.00g/ml of benomyl. Findings of the study indicated that integrated pest management could be adopted in disease suppression.

Ekundayo and Oni (2011) evaluated response of maize to inoculation with *Glomus mosseae*, and arbuscular mycorrhiza (AM) fungus and NPK fertilizer application in the presence of a commonly used herbicide, atrazine at three different concentrations. It was observed that increased atrazine concentrations, population of non-AM fungi increased than that of AM fungi decreased except in soil inoculated with *G. mosseae* and NPK. In the absence of atrazine, the height of maize seedling was highest (145.2cm) in the soil where NPK fertilizer was applied whereas in the absence of atrazine (0.00g/ml), the height was 113.0 cm. The root length of maize seedling inoculated with mycorrhizal (*G. mosseae* and NPK fertilizer at 0.010g/ml of atrazine was the highest. The highest amount of Na (0.39% and 12.50mg/kg) were recorded in soil where NPK fertilizer was applied with 0.010g/ml of atrazine. On the other, there was reduction of N and P (0.20 and 2.08mg/kg) in this same soil at 0.020g/ml of atrazine. There was increase in AM fungi spore count in soil inoculated with *G. mosseae* than uninoculated soil. The AM fungi spore count increased in the presence of NPK fertilizer at 0.00g/ml to 306.0 at 0.020g/ml of atrazine. In the absence of fertilizer, the mycorrhizal load decreased from 227at 0.00g/ml to 141 at 0.020g/ml of atrazine. Atrazine eliminated some species of soil fungi such *as Fusarium solani*, *Aspergillus* and *Neurospora*

crassa while the highest fungal count was obtained from *Glomus mosseae* and NPK treated plant at highest concentration of atrazine. The study concluded that lower concentrations of atrazine would enhance AM fungi than higher concentrations.

Also, **Ekundayo *et al.*** (2012) observed that benomyl consistently abolished penicillin production by *Penicillium italicum* and *P. oxalicum* at standard concentrations. However, at sub-inhibitory doses, *P. oxalicum* produced metabolites that inhibited *S. aureus* and *S. paratyphi* — organisms resistant to the metabolites produced in untreated conditions. The paper explicitly noted that this extended activity could not be attributed to penicillin alone, implicating benomyl-mediated genetic modification in the synthesis of previously uncharacterized secondary metabolites.

Ekundayo and Hassan (2012) determined both *in vitro* and *in planta* antifungal efficacy of camazeb, a fungicide used as a protectant foliar spray to crops (including tomato) to control a wide range of fungal diseases including damping off disease of tomato caused by *Rhizoctonia solani*. Their results indicated that damping off disease led to the death of tomato seedlings where *R. solani* was inoculated. It was observed that plants were healthy at 0.25g/100ml of camazeb in soil inoculated with *R. solani*. However, higher concentrations of camazeb (2.00 and 400g/100ml) were detrimental to tomato seedlings. Colony count of rhizosphere bacteria reduced from $14 \pm 4.0 \times 10^3$ cfu/g at 0.00g/100ml to $5 \pm 1.0 \times 10^3$ cfu/g at 4.00g/10 0ml of camazeb. Camazeb at all concentrations had inhibitory effects on the radial growth of *R. solani*.

In another study, **Agboola *et al***. (2018) investigated the effects of glyphosate, the world's most widely used herbicide on rhizosphere microorganisms and their phosphate-solubilising potential in cowpea cultivation. This field experiment, conducted on land at the

Federal University of Technology, Akure, used four concentrations of glyphosate (0.00, 0.50, 1.00, and 3.00 mg/ml) in a completely randomised factorial design, with cowpea harvested after 30 days. Ten bacteria and three fungi were isolated from the glyphosate-treated rhizosphere, including *Bacillus cereus, B. subtilis, Micrococcus luteus, Pseudomonas aeruginosa, Proteus mirabilis, B. pumilus, Staphylococcus aureus, Aspergillus flavus, Rhizopus nigrificans*, and *A. saprophyticus*. Bacterial and fungal populations decreased as glyphosate concentration increased (consistent with the literature on herbicide-induced microbial suppression (Santos *et al*., 2004, 2006; Cervelli *et al*., 1978), but the critical finding was organism-specific resilience in phosphate solubilisation capacity.

From the tricalcium phosphate solubilisation assay, *Bacillus cereus* achieved the highest single-day solubilisation among untreated-soil isolates (515.78 ± 0.06 gl^{-1} on Day 1), but the pH did not drop consistently with increased solubilisation, suggesting that the observed phosphate release was not primarily through organic acid production and that this organism does not qualify as a true phosphate-solubilising microorganism under the criterion of concomitant pH reduction. *Bacillus subtilis* and *P. mirabilis*, by contrast, showed genuine pH-linked phosphate solubilisation, even at the highest glyphosate concentration (3.00 mg/ml), confirming their capacity to function as PSM even under herbicide stress. *Proteus mirabilis* showed the highest phosphatase activity (23.157 mM/min/ml at 30 hours), and *Aspergillus saprophyticus* showed the highest phosphatase activity among the fungi (35.263 mM/min/ml at 72 hours).

Insecticide residues are ubiquitous in intensively cultivated soils, and their effects on beneficial soil fungi are rarely systematically evaluated. Based on this, **Oladapo *et al*.** (2020) examined the effects

of lambda-cyhalothrin and dimethoate on rhizosphere fungi and their phosphate-solubilising potential. All the isolated rhizosphere fungi: *Rhizopus stolonifer*, *Aspergillus niger*, *A. fumigatus*, *A. terreus*, *Trichoderma viride*, *Arthroderma falvum*, and *Fusarium oxysporum* exhibited phosphate-solubilising capacity, confirming the widespread nature of this capability in the cowpea rhizosphere mycobiome. *Trichoderma viride* emerged as the outstanding performer, achieving a solubilisation index of 2.82 at dimethoate concentration of 12.5 ml/L on the 90th day of harvest — the highest SI recorded across all species and all treatment conditions (Table 2).

The most striking finding was that fungal loads in the rhizosphere increased with increasing insecticide concentration and with the days of cowpea harvest. At the highest dimethoate concentration (37.5 ml/L), fungal counts were highest at the 90th day of harvest. This stimulatory response whereby sub-lethal doses of a toxic substance enhance rather than suppress biological function has been documented for other pesticides (Pozo *et al*., 1995; Srinvasulu and Ortiz, 2017;) and is consistent with the capacity of some microbial flora to use lambda-cyhalothrin and dimethoate as carbon sources (Peacock *et al*., 2014).

Table 2 presents the phosphate solubilisation indices. *Trichoderma viride* emerged as the outstanding performer, achieving a solubilisation index (SI) of 2.82 at dimethoate concentration of 12.5 ml/L on the 90th day of harvest — the highest SI recorded across all species and all treatment conditions. Optimisation studies established that *Trichoderma viride* produced phosphatase optimally at pH 6.5 — a value that corresponds to the pH range of most cultivated soils in South-West Nigeria — at a temperature of 30°C, and with a combination of glucose and dextrose as carbon sources, and yeast extract with ammonium sulphate as nitrogen sources.

Table 2: Phosphate solubilisation indices of rhizosphere fungi from insecticide-treated cowpea soil

Fungal Isolate	Best SI	Insecticide / Conc. (ml/L)	Day of Harvest	Opt. pH (submerged ferm.)	Opt. Temp. (°C)
Trichoderma viride	2.82	Dimethoate 12.5	90	6.5	30
Aspergillus niger	2.34	Dimethoate 12.5	90	—	—
Aspergillus fumigatus	2.34	Dimethoate 12.5	90	—	—
Aspergillus terreus	2.27	Cyhalothrin 37.5	90	—	—
Rhizopus stolonifer	2.22	Cyhalothrin 12.5	70	—	—
Fusarium oxysporum	2.13	Control (0.00)	50	—	—

SI = solubilisation index = (colony diameter + halo zone diameter) / colony diameter. Higher SI indicates greater phosphate solubilisation.

The combined findings of the cowpea ecosystem studies deliver a coherent and practically important message: at recommended field concentrations, benomyl, atrazine, glyphosate, lambda-cyhalothrin and dimethoate did not eliminate the phosphate-solubilising microorganisms of the cowpea rhizosphere. The critical practical implication is that *T. viride*, *B. subtilis*, and *P. mirabilis* are candidates for development as commercial biofertilizer inoculants adapted for use in agrochemical-treated Nigerian soils.

Oladapo *et al*. (2021) in a complementary study examined the direct phytotoxicological consequences of lambda-cyhalothrin and dimethoate application to cowpea plants, assessing growth parameters including plant height, leaf area, stem girth, number of leaves, days to first flowering, and pod characteristics at different insecticide concentrations across cowpea growth stages This study was conducted in pots containing 10 kg of topsoil per pot, with insecticide applications at concentrations of 12.5, 25.0, and 37.5 ml/L of both insecticides independently and in combination. The results revealed that both insecticides caused dose-dependent reductions in vegetative growth parameters at the highest concentrations (37.5 ml/L), with the combined insecticide treatment producing the greatest suppression of plant height and leaf area. Days to first flowering were delayed by approximately 3–5 days in high-concentration treatments relative to the untreated control, and pod weight was significantly reduced at 37.5 ml/L. However, at 12.5 ml/L (the lowest tested concentration and one consistent with field application rates recommended by manufacturers) growth parameters were not significantly different from the control, confirming that this concentration represents the practical safety threshold for cowpea phytology as well as for rhizosphere microbiology. The coherence between the phytological safety threshold (12.5 ml/L for insecticides; 0.10–0.20 g/ml for benomyl) and the microbiological safety window is scientifically significant: it suggests that the agronomic dosing rates that protect plant growth also tend to preserve the rhizosphere microbial community. This alignment may not be coincidental as plants that are themselves stressed by high pesticide concentrations likely produce fewer and qualitatively different root exudates, indirectly altering the rhizosphere community in ways that compound the direct toxic effects on beneficial microorganisms.

4.2 Biodegradation — Harnessing Nature's Chemical Engineers (Indigenous Soil Microorganisms)

Madam Vice Chancellor, **Onifade *et al***. (2007) established the baseline biodegradation capacity of the indigenous microbial community in crude-oil-contaminated soil from the Gokana Local Government Area of Rivers State. Using remediation enhanced natural attenuation (RENA), a land-farming technology that relies on natural microbial processes enhanced by nutrient amendment and aeration, the study monitored total heterotrophic bacteria (THB) counts and physicochemical properties across eighteen weeks of remediation. Two fungi, *Articulospora inflata* and *Zoopage mitospora*, and five bacterial genera (*Lactobacillus, Arthrobacter, Bacillus, Pseudomonas and Micrococcus*) were isolated and identified as hydrocarbon utilizers from the contaminated site. Critically, this study documented the differential response of microbial communities across plots with varying degrees of contamination and at different points in the remediation period, establishing that the indigenous microbial community, when provided with appropriate conditions, possesses the metabolic diversity to initiate meaningful petroleum hydrocarbon degradation without the introduction of external organisms (Figures 1a and b).

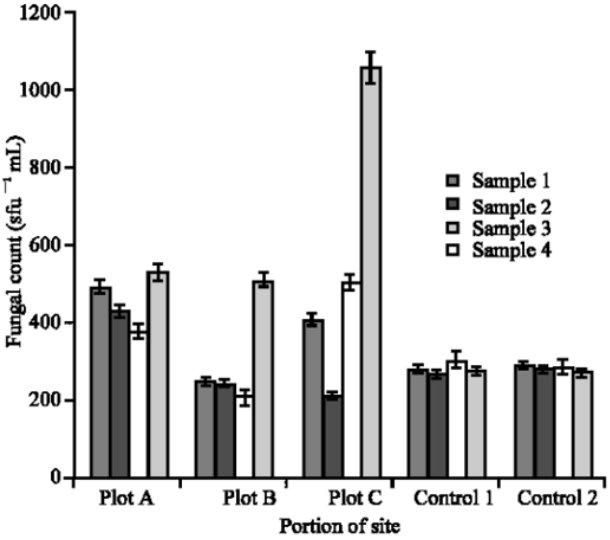


Figure 1a: Trend of change in the total heterotrophic bacterial population

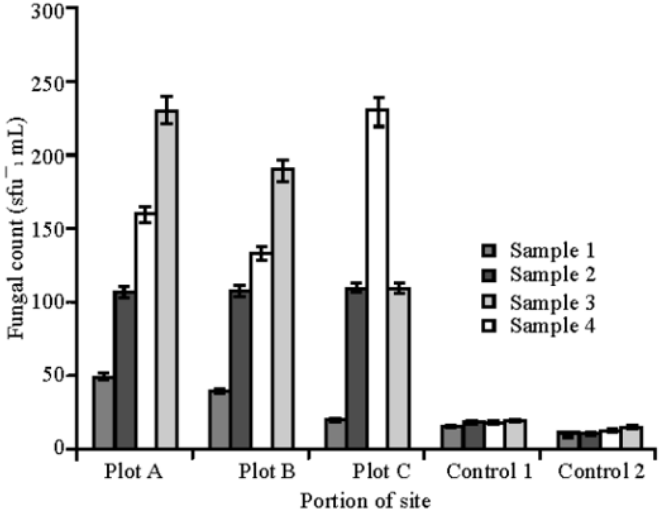


Figure 1b: Trend of change in the hydrocarbon utilizing fungal population

4.2.1 Fungi as Biodegraders

Ekundayo *et al.* (2012) compared the degradative ability of harvested (centrifuged and washed cell pellets) versus non-harvested (intact culture biomass) cells of six fungi (*Mycotypha microspora, Penicillium italicum, Botrytis cinerea, Gliocladium deliquescens, Verticillium albo-atrum, and Aspergillus niger*) of soil origin on Bonnylight crude oil over 20 days, measured by optical density at 540 nm. Non-harvested cells consistently outperformed harvested cells by a factor of 2 to 3 across all species and all time points, with *Aspergillus niger* showing the most dramatic difference: non-harvested cells reached OD 0.82 ± 0.21 by Day 20, compared with harvested cells' OD 0.40 ± 0.03 — a doubling of degradative capacity attributable to the retention of intact secretory apparatus, enzyme complement, and co-factor pools in the non-harvested cells. By contrast, isolates from uncontaminated reference soils showed declining OD values over the 20-day period, reflecting the absence of the metabolic adaptation that characterises pollution-selected strains. This contrast between adapted and non-adapted populations is the conceptual foundation of the entire bioremediation programme: contaminated environments, though degraded, are not microbiologically barren. They harbour the very organisms whose capabilities are most relevant to their own restoration. Therefore, non-harvested cells can be employed in bioremediation of Bonnylight crude oil.

In an allied study, **Ekundayo** and Osunla (2013) demonstrated that fungi isolated from automobile workshop soils in Akure - soils heavily contaminated with spent engine oil and Bonny light crude oil were found to produce phytase, the enzyme that hydrolyses phytate complexes to release inorganic phosphate. *Aspergillus flavus* was the maximum phytase producer, optimally active at pH

5.0 and 50°C. The study demonstrated that the fungal isolate with the highest phytase activity correlated with enhanced hydrocarbon-degrading capacity: *Aspergillus niger*, the most competent crude oil degrader, also produced phytase — suggesting that phosphorus liberated enzymatically may fuel the metabolic activity of the hydrocarbon-degrading microbial community (Figures 1 and 2).

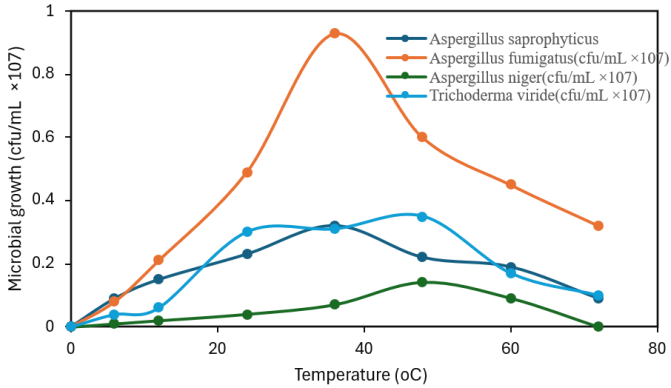


Figure 1: Phytase activities of fungi isolates

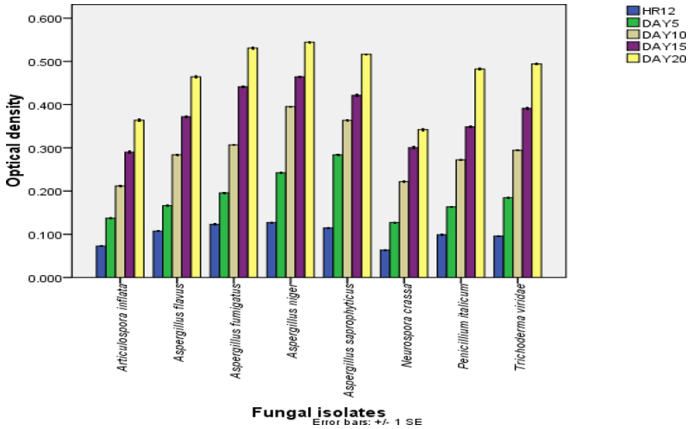


Figure 2: Optical density of fungal isolates from contaminated soil at different hours of biodegradation of used engine oil.

4.2.1.1 *Pleurotus* Mycoremediation: Mushroom as Environmental Engineer

White rot fungi (WRF) are increasingly being investigated and used in bioremediation, because of their ability to degrade an extremely diverse range of very persistent or toxic environmental pollutants (Isihuenmen *et al*., 2003) Adenipekun and Isikhuemen (2008) reported that engine oil contaminated soil incubated with *Lentinus squarrosulus* resulted in an increase in nutrient contents and a high percentage degradation of total petroleum hydrocarbon after 90 days of incubation. The use of macrofungi is expected to be relatively economical as they can be grown on a number of inexpensive agricultural or forest wastes such as corncobs and sawdust.

In a study, **Ekundayo** (2014) inoculated soils contaminated with 10, 15, and 20 crude oil and with 10, 15, and 20% engine oil with grower mash of the two *Pleurotus* species and monitored for total petroleum hydrocarbon (TPH) content over three and six months. The most dramatic findings in the biodegradation subtheme concern the use of *Pleurotus ostreatus* (oyster mushroom) and *P. pulmonarius* as mycoremediation agents

The study also determined the effects of the selected white rot fungi on the physiochemical and nutrient properties of the contaminated soils. The results showed that the organic matter of soil contaminated with crude oil and inoculated with *P. ostreatus* was higher except at concentration 30% after three months. It was also observed that the organic matter of soil contaminated with from zero to 20% concentration used engine oil and inoculated with *P. ostreatus* was higher at six months. Also, there was a progressive increase in the organic matter when *P. pulmonarius* was inoculated after six months. As the percentage of crude oil increased, there was increase in percentage carbon (% C) in soils inoculated with *P.*

ostreatus after 3 and 6 months. Percentage carbon also increased in soil contaminated with engine oil and inoculated with *P. pulmonarius* after 6 months. However, there was slight decrease in % C of all the soils with *P. pulmonarius* when compared with *P. ostreatus* after 3 and 6 months of contamination with crude and engine oils. A general decrease was observed in percentage nitrogen (% N) as the concentration of crude oil applied increased in soils treated with *P. ostreatus* and *P. pulmonarius* after 3 months. The % N of soils treated with crude oil and inoculated with *P. ostreatus* was higher than that inoculated with *P. pulmonarius* after 3 and 6 months. There was a progressive decrease in nitrogen content of soil with increase in concentration of used engine oil and inoculated with *P. ostreatus* whereas that of *P. pulmonarius* increased after three months from concentration 5 to 20. Also, the nitrogen content of soil inoculated with *P. pulmonarius* was higher than that of *P. ostreatus* after six months. Generally, there was increase in phosphorus content of soil samples contaminated with crude oil as well as engine oil and inoculated with *P. ostreatus and P. pulmonarius* after the third and sixth months from concentrations 5% to 20% although the phosphorus content of *P. ostreatus* inoculated soil was higher.

From the key remediation data (Table 3), *Pleurotus ostreatus* reduced TPH in soil contaminated with 20% crude oil from 165,724 mg/kg to 14,581 mg/kg over six months — a reduction of 91.2% that is competitive with the performance of expensive physicochemical remediation technologies. Engine-oil-contaminated soil showed an equivalent 90.7% reduction in TPH when treated with *P. ostreatus*. These are not incremental improvements; they represent a near-complete biological clean-up of severely contaminated soil within a six-month treatment window.

Table 3: Total petroleum hydrocarbon (TPH) reduction in crude-oil- and engine-oil-contaminated soil inoculated with *Pleurotus* species over six months.

Treatment	Initial TPH (mg/kg)	3 months (mg/kg)	6 months (mg/kg)	% Reduction (6 month)	Treatment
20% Crude oil - *P. ostreatus*	165,724	~85,000	14,581	91.2	20% Crude oil - *P. ostreatus*
20% Crude oil - *P. pulmonarius*	165,724	~105,000	~25,000	~84.9	20% Crude oil - *P. pulmonarius*
20% Engine oil - *P. ostreatus*	74,816	~40,000	6,972	90.7	20% Engine oil - *P. ostreatus*

POCO = *P. ostreatus* on crude oil; PPCO = *P. pulmonarius* on crude oil.

Ekundayo *et al.* (2014a) also subjected the remediated mushrooms themselves to rigorous safety assessment - an ethical necessity given that *Pleurotus* species are edible and might be harvested from remediation plots by surrounding communities. Albino rats fed on *P. ostreatus* grown on crude-oil-contaminated soil (POCO treatment) showed normal haematological profiles with no anaemia - a finding that supports the relative safety of this treatment. Rats fed with *P. pulmonarius* grown on crude-oil-contaminated soil (PPCO treatment), however, showed elevated white blood cell counts and neutrophils, indicating systemic inflammation, and histopathological examination revealed hepatic cell vacuolation, renal cell infiltration and glomerular detachment, myocardial haemorrhage, and intestinal wall damage.

The safety assessment finding carries a firm practical message: *P. ostreatus* may be used for mycoremediation of crude-oil-contaminated soil with relatively low risk of bioaccumulation of toxic compounds in the fruiting body. *Pleurotus pulmonarius*, though equally effective at TPH reduction, it caused histopathological damage in mammalian consumers. Bioremediation programmes should explicitly distinguish between these two species and prohibit the human consumption of fruiting bodies from PPCO treatment plots.

4.2.2 Bacteria as biodegraders

Complementary studies by **Ekundayo *et al*.** (2014b, 2014c) demonstrated that *Pseudomonas aeruginosa, P. fluorescens,* and *P. stutzeri* (Table 4) as well as *Bacillus* species isolated from car workshop soils, market wastewater, and dam water in Akure, could degrade both petroleum products as well as pesticides; benomyl, mancozeb and herbicides (Figure 3).

Table 4: Biodegradative ability of *Pseudomonas* isolates on petroleum products measured by optical density (OD) after 5 days of incubation.

Isolates	Diesel	Petrol	Kerosene	Engine oil
P. aeruginosa (MW)	0.41±0.02	7.14±0.00	0.46±0.01	3.19±0.01
P. aeruginosa (SW)	0.22±0.00	1.21±0.01	0.31±0.01	1.72±0.02
P. fluorescens (DS)	1.02±0.02	1.35±0.02	0.25±0.01	0.35±0.01

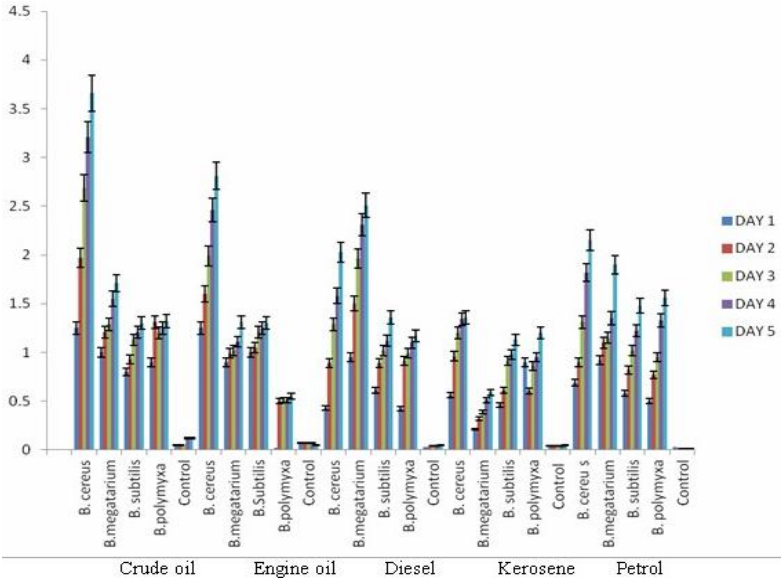


Figure 3: Degradative abilities of *Bacillus* species on selected petroleum hydrocarbon

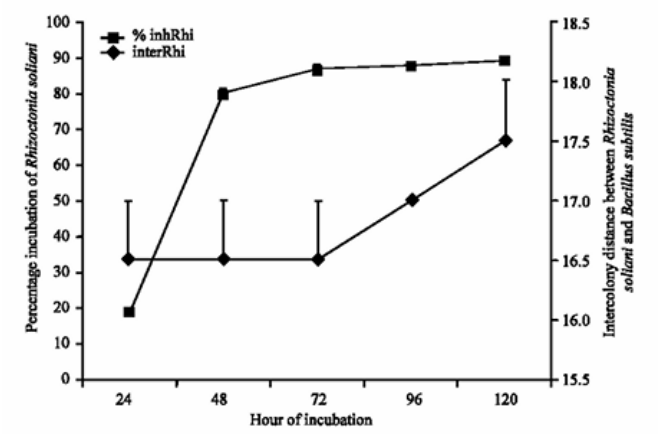
In a 2021 study, **Onifade *et al.*** opened a new ecological dimension. The rhizosphere soils of cocoa, orange, and teak plantation trees at Idanre, Ondo State, were found to harbour hydrocarbon-degrading bacterial communities distinct in composition. *Enterobacter agglomerans* isolated from the teak plantation rhizosphere emerged as the most effective degrader of Forcados blend crude oil over a thirty-day incubation period, with optical density measurements demonstrating progressive hydrocarbon consumption significantly exceeding that of all other isolates. This finding opens the underexplored ecological dimension of plantation rhizospheres as reservoirs of high-performance environmental bacteria. In another study, **Ekundayo** *et al*. (2024) observed that a decrease in the amount of organic carbon, organic matter, nitrogen, potassium and sodium content of the soil after the treatment. **Ogunsakin *et al.*** (2024) and **Oyewumi *et al.*** (2024) demonstrated that silver nanoparticles

(AgNPs) synthesized extracelluarly by different fungal and bacterial isolates could be harnessed in bioremediation of crude oil polluted soils.

4.3 Biological Control: Deploying Microbial Antagonists from FUTA Environs against Phytopathogens

Fungal phytopathogens are among the biotic factors that cause serious losses to agricultural crops. Several studies have shown the effectiveness of various fungicides on fungal phytopathogens. However, exclusive reliance on fungicides is discouraged because of their cost, environmental hazards, and deleterious effects on non-target organisms. Therefore, biological control of plant diseases is advocated instead of chemical pesticides. Biological control, the deliberate use of one organism to suppress another offers a pathway to reducing the application of synthetic chemical pesticides while maintaining adequate protection of crops against devastating fungal pathogens.

Madam Vice Chancellor, **Ekundayo *et al.*** (2011) investigated the antifungal properties of microbes obtained from corn cob on fungal phytopathogens. The results of the investigation showed that were progressive increase in inhibition percentages *Fusarium solani* by *B. subtilis* over five days of dual culture, reaching 89% inhibition by Day 5 (Figures 4). This progressive increase confirms that the antagonism may be mediated by secreted metabolites that accumulate in the growth medium over time, rather than by direct physical competition for space or nutrients. *B. subtilis* is well established as a producer of lipopeptide antibiotics including iturin, fengycin, and surfactin, which disrupt fungal cell membranes (Brace *et al*., 1998). The progressive inhibition kinetics observed in this study are consistent with secreted compound accumulation.



Figures 4: Inhibition of *Rhizoctonia solani* by *Bacillus subtilis* on PDA at 25°C.

Values are means of two replicates while vertical bars represent standard error. InhRhi: Percentage inhibition of *Rhizoctonia solani* by *B. subtilis*, InterRhi: Intercolony distance between *Rhizoctonia solani* and *B. subtilis*

In another study, **Ekundayo** and Hassan (2012) established that rhizosphere bacteria of tomato had inhibitory effects on *R. solani*. However, *Pseudomonas aeruginosa* and *Bacillus subtilis* were the most effective with pathogen inhibition of 37.80 and 28.10 mm respectively which was higher than that of the fungicide; camazeb even at higher concentration.

Sclerotium rolfsii (the causal agent of southern blight, a devastating disease that attacks more than 500 plant species including cowpea, tomato, groundnut, and cassava) is one of the most damaging soil-borne fungal pathogens in Nigerian agriculture. *Trichoderma viride* were obtained from three ecologically distinct sources: maize plant soil (V_1), ginger plant soil (V_2), and abattoir soil (V_3), and their antagonistic activity against *S. rolfsii* was evaluated at 37°C across pH levels of 4, 5, 7, and 9 (**Ekundayo *et al***., 2015). The key finding

is that biocontrol efficacy is context-dependent: *T. viride* isolated from abattoir soil (V_3) achieved the highest inhibition across all pH levels, with a peak of 88% inhibition at pH 4 — an acid condition typical of many Nigerian red tropical soils. By contrast, the ginger-soil isolate (V_2) was the least effective biocontrol agent across all pH conditions tested (Table 5). This finding has direct implications for sourcing of biocontrol inoculants: ecotype matters, and the assumption that any *T. viride* isolate will perform equivalently in the field is not supported by experimental evidence.

Table 5: Percentage inhibition of *Sclerotium rolfsii* by three *Trichoderma viride* isolates at 37°C and varying pH levels

T. viride Isolate Source	pH 4 (% inhibition)	pH 5	pH 7	pH 9	Field Application Notes
Maize plant soil (V_1)	66.7	71.2	75.8	58.3	Best at neutral-slightly acid soils
Ginger plant soil (V_2)	52.1	58.6	64.4	49.7	Weakest performer — avoid strongly acid soils
Abattoir soil (V_3)	88.0	82.3	78.1	71.4	Outstanding in acid soils — ideal for tropical SW Nigeria

In planta experiments confirmed that *T. viride* not only suppressed *S. rolfsii* but actively promoted plant growth in tomato seedlings, with fresh, root fresh, and dry weights significantly higher in *T. viride*-treated, *S. rolfsii*-inoculated plants than in the pathogen-only control (Table 6). This growth-promotion effect (mediated by the production of phytohormones, improvement in water and nutrient uptake, and induction of systemic resistance (Chet *et al*., 2007; Chutrakul *et al*., 2008)) reinforces the dual function of *Trichoderma* as both biocontrol agent and plant growth promoter.

Table 6: Growth characteristics of tomato plant grown under different conditions on the 10th day

Treatment	Plant height(cm)	Leaf number
St	7.20 ± 0.12	St
StSr	7.00 ± 0.17	StSr
StSrTm	8.00 ± 0.21	StSrTm
StSrTg	8.20 ± 0.28	StSrTg
StTm	7.70 ± 0.14	StTm
StTg	8.00 + 0.21	StTg

Key: St= (control); StSr= soil treated with S. rolfsii; StSrTm= soil treated with S. rolfsii and T. viride (maize cob); StSrTg= soil treated with S. rolfsii and T. viride (ginger soil); StTm= soil treated with T. viride (maize cob); StTg= soil treated with T. viride (ginger soil).

Ekundayo *et al.* (2016) characterized chitinase from FUTA-sourced isolate – *T. viride* as one of the mechanisms of its antifungal potencies. *Trichoderma viride* recovered from maize cob within the FUTA environs produced chitinase with progressive activity increase to the fiftieth hour of incubation, an optimum temperature of 50°C and pH 5, and enzyme activity maximally stimulated by $CaCl_2$ (Figures 5a-c).

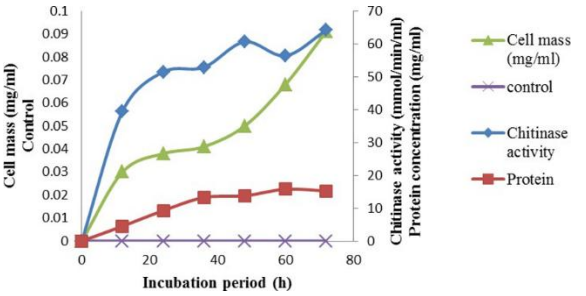


Figure 5a: Chitinolytic activity of *T. viride* isolated from maize cob

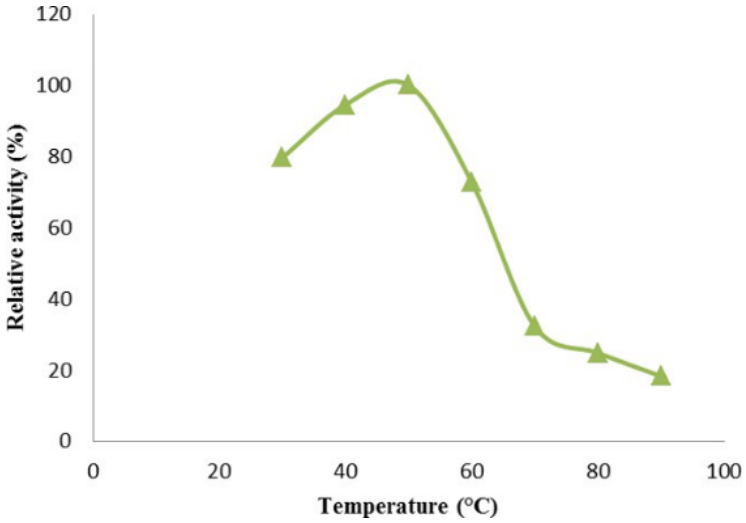


Figure 5b: Effect of temperature on the chitinolytic activity of *T. viride*

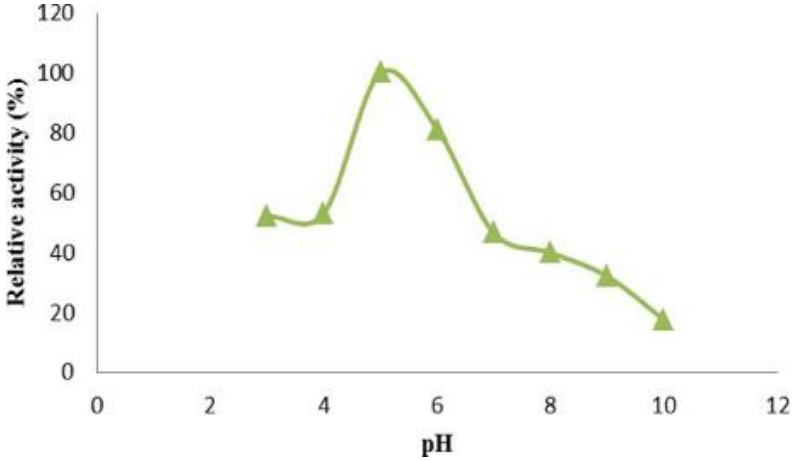


Figure 5c: Effect of pH on the chitinolytic activity of *T. viride*

Three-stage purification — ammonium sulphate precipitation, DEAE-cellulose ion-exchange chromatography, and Sephadex G-100 gel filtration — (Figure 5d) yielded an 8.5-fold increase in specific activity with 11.84% recovery. This was the first report of chitinase production from *T. viride* isolated from maize cob, establishing an ecological provenance highly relevant to Nigerian agricultural waste streams.

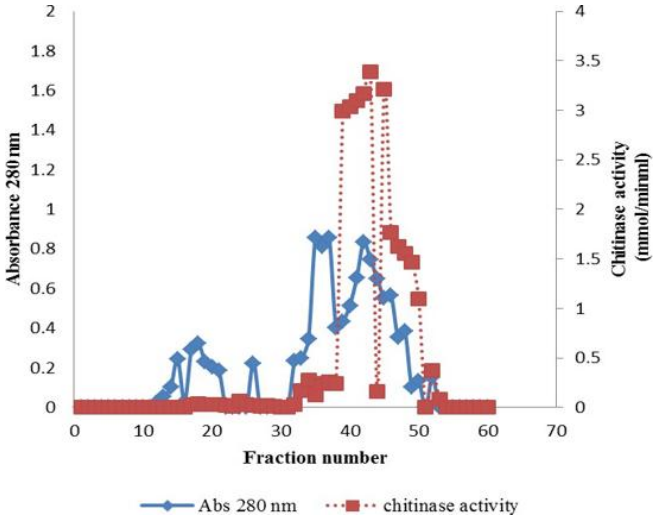


Figure 5d: Purification of chitinase produced by *T. viride*

In another study, **Ekundayo *et al*.** (2017) observed that *Bacillus subtilis* was antagonistic to *A. niger* and *A. flavus* while *B. firmus*, *B. sphaericus*, *B. licheniformis* and *B. endophyticus* were not inhibitory to the fungal isolates. *Bacillus subtilis* obtained in this study can be used to control *Aspergillus niger* and *A. flavus.*

Ekundayo *et al*. (2018) demonstrated the protective function of *T. viride* against *Sclerotium rolfsii* on okra (*Abelmoschus esculentum*) under greenhouse conditions. Comparing sterile and non-sterile soil

treatments across seven experimental groups, we found that non-sterile soil consistently produced healthier plants and higher fruit yields than sterile soil across all treatment conditions. This finding carries a theoretical implication of importance: the biocontrol efficacy of *T. viride* is not merely a property of the organism in isolation, but of the organism operating within an intact, diverse soil microbial community. Sterilization destroys the synergistic network that amplifies biocontrol function. This conclusion directly challenges the practice of evaluating biocontrol preparations in sterilized laboratory conditions and argues for mandatory field-realistic testing protocols.

Nigeria's soils harbour a remarkable diversity of *Rhizobium* species, the nitrogen-fixing, root-nodule-forming bacteria that constitute one of the most economically important symbioses in agriculture. The biological fixation of atmospheric nitrogen by Rhizobium-legume systems reduces or eliminates the need for synthetic nitrogen fertiliser, one of the costliest inputs in smallholder cowpea production. However, a few environmental factors: temperature extremes, pH variation, salinity, heavy metal contamination, and antibiotic exposure are known to impair the symbiotic efficiency of *Rhizobium*. Characterisation of indigenous Rhizobium populations for their tolerance of these adverse conditions is a prerequisite for selecting commercially viable inoculant strains (Singh *et al*., 2008).

Ekundayo *et al*. (2018) isolated *Rhizobium* species from root nodules of cowpea (*Vigna unguiculata*) and common bean (*Phaseolus vulgaris*) in Akure, Nigeria and evaluated the environmental tolerance of these *Rhizobium* species *(Rhizobium* sp., *Mesorhizobium* sp., and *Sinorhizobium* sp.) across a matrix of temperature, pH, salt concentration, heavy metal, and antibiotic challenges. The most robust isolate was *Rhizobium* sp., which

showed resistance to all ten antibiotics tested (tarvid, gentamicin, ciprofloxacin, augmentin, amoxicillin, streptomycin, septrin, chloramphenicol, pefloxacin, and sparfloxacin) and tolerated NaCl concentrations up to 4%, the threshold associated with moderate soil salinity in coastal farming areas. The wide range of antibiotic tolerance may reflect a mechanism by which rhizobia overcome the antagonism exerted by other soil organisms, including Actinobacteria, and may partially explain the ecological success of inoculant strains under competitive field conditions (Lacerda *et al*., 2004). All isolates grew optimally at 28°C (the mean temperature across much of south-west Nigeria's main growing season) but growth was severely impaired at 50°C, with no colonies recovered. Growth optima at neutral pH 7.0 were consistent across all three species, although all isolates demonstrated some growth at pH 4.0 and 9.0 (Table 7), suggesting tolerance of the pH range encountered across Nigeria's diverse agroecological zones.

Table 7: Environmental tolerance profile of *Rhizobium* species isolated from cowpea root nodules in Akure, Nigeria

Rhizobium species	Opt. Temp. °C)	Opt. pH	NaCl Tolerance (max %)	Antibiotic Resistance	Inoculant Suitability
Rhizobium sp.	28	7.0	4.0%	All 10 tested	Excellent (most robust)
Mesorhizobium sp.	28	7.0	≤ 2.0%	Sensitive to pefloxacin, sparfloxacin	Good (moderate salt tolerance)
Sinorhizobium sp.	28	7.0 (highest)	≤ 1.0%	Sensitive to pefloxacin only	Moderate (pH-specialised)

Another dimension of the biocontrol programme demonstrated that *Pseudomonas pseudomallei*, isolated from benomyl-treated rhizosphere soil achieved 60% inhibition of *Sclerotium rolfsii* within

24 hours of dual culture among other species (**Ekundayo** and Alaofin, 2019). *Pseudomonas cepacia* isolated from the rhizosphere of soil treated with both mancozeb and benomyl gives 25.00% inhibition against *S. rolfsii* at 24 hours, 5.00% at 48 hours and 5.20% inhibition at 72 hours. *Pseudomonas capacia* inhibited *Collectotricum capsici* by 80% on 24 hours of incubation. The results of the antagonistic activities shown by the *Pseudomonas* species were in agreement with the work of Susilowath and Wiyono (2011). This study has established that *Pseudomonas cepacia, P. stutzeri* and *P. pseudomallei* may serve as a good biocontrol agent for *Rhizotonia solani*.

Afolayan *et al.* (2020) broadened the taxonomic scope significantly by screening sixteen fungal species isolated from the rhizospheres of mango, cassava, guava, banana, and fishpond sediment within FUTA Farm for chitinolytic activity. *Aspergillus nidulans* emerged as the superior chitinase producer, yielding a thermostable enzyme active across the temperature range 30°C to 70°C, with maximum activity at 50°C and an 8.86-fold purification at 9.74% recovery. The enzyme's remarkable stability across a wide pH range (4.0 to 9.0) over two-hour incubation periods represents a significant practical advantage for biocontrol formulation: a candidate biofungicide must remain active across the variable pH conditions of Nigerian agricultural soils.

Ekundayo *et al.* (2022) demonstrated that crude chitinase from *Streptomyces albus* inhibited all five major crop pathogens tested, including *Fusarium graminearum, Rhizoctonia solani, Botrytis cinerea, Aspergillus fumigatus, and Penicillium expansum* (Table 8).

Table 8: Comparative inhibitory activity of crude chitinase from *Streptomyces albus* and mancozed against phytopathogenic fungi

Phyto-pathogenic Fungus	Crude Chitinase Zone (mm)	Mancozeb (positive control, mm)	Commercial significance	Disease caused
Fusarium graminearum	10.74 ± 0.28	22.40 ± 0.36	Fusarium head blight - major cereal threat	Ear rot, crown rot
Rhizoctonia solani	9.22 ± 0.14	20.80 ± 0.22	Sheath blight - rice, soya	Root rot, damping-off
Botrytis Cinerea	8.10 ± 0.22	19.60 ± 0.30	Grey mould - 200+ host crops	Post-harvest fruit rot
Aspergillus fumigatus	8.74 ± 0.18	21.20 ± 0.26	Aspergillosis - human /ani-mal pathogen	Invasive infection
Penicillium expansum	7.86 ± 0.12	18.40 ± 0.20	Blue mould - post-harvest	Fruit rot, patulin production

Values are zones of inhibition (mm), mean ± SEM (n = 3). All values significantly different from zero at $P < 0.05$.

Although mancozeb (a commercial synthetic fungicide) produced larger inhibition zones across all pathogens, the significance of these findings lies not in competition with synthetic alternatives but in the proof of concept that a crude, unoptimised enzymatic preparation from a locally isolated *Streptomyces* species can inhibit all five target pathogens simultaneously. With appropriate purification, formulation, and optimisation, chitinase from Nigerian *Streptomyces* species may achieve the potency necessary for integration into integrated disease management programmes. The broad-spectrum antifungal activity of a single soil-sourced enzyme preparation against five pathogens of global economic significance is precisely the performance profile required of a candidate commercial biofungicide.

4.4 Antimicrobial activities of environmental microbes

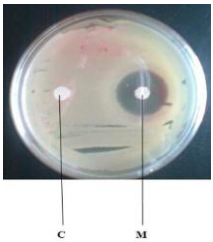
Madam Vice Chancellor, **Ekundayo *et al.*** (2014b) employed agar well diffusion method to determine the antimicrobial activities of *Pseudomonas* spp. isolated from the different samples against some clinical bacterial isolates; *Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae, Proteus mirabillis* and *Serratia marcescens* were susceptible to *Pseudomonas* isolates while *Staphylococus aureus* was resistant to the isolates. *Klebsiella pneumoniae* was resistant to *P. aeruginosa* (MW) but showed fair resistance to *P. aeruginosa* (SW) and *P. fluorescens* (DS). All the fungi except *Candida albicans* were susceptible to *Pseudomonas* spp**.**

Conversely, **Ekundayo *et al*.** (2014c) while investigating the antibacterial potential of different species of *Bacillus* observed that only *Staph aureus* was inhibited by *B. polymyxa*. Yilmaz *et al*. (2006) also observed that *S. aureus* was resistant to *B. cereus* and *B. megaterium* although Perez *et al*. (1993) showed the sensitivity of *S. aureus* to various strains of *Bacillus* species. *Oscariz et al*. (1999) isolated and identified a bacteriocin-producing strain of *B. cereus* from a soil sample which was active against most Gram-positive but not Gram-negative bacteria.

The global pipeline of novel antibiotic compounds is critically depleted. Of the antibiotics that were in clinical use in 2024, an alarmingly high proportion were developed before 1980 (WHO, 2021). Yet the soil bacterium, *Streptomyces* has historically been the most productive single genus for antibiotic discovery: streptomycin, erythromycin, chloramphenicol, tetracycline, and vancomycin itself were all derived from *Streptomyces* species.

Ekundayo *et al*. (2014d), and **Ogundare *et al***. (2015) investigated whether Nigeria's diverse soils harbour *Streptomyces* species producing metabolites active against different array of bacterial

isolates as well as against dermatophytes (Table 9, Plate 8). Different species of *Streptomyces* extract achieved inhibition zones exceeding 30 mm against Gram-negative clinical pathogens for which commercial streptomycin was ineffective. The infrared spectroscopy revealed the presence of four important functional groups; hydroxyl, carbon-hydrogen, carbonyl and aromatic groups. The nucleotide sequence of the 16S RNA showed that the most potent isolate showed 83% identity with *Streptomyces albus.*



C = Control, M= Metabolite

Plate 8: Antimicrobial activities of partially purified metabolite of *S. albus* against *S. aureus*

Table 9: Antimicrobial activities of crude metabolite produced by *Streptomyces albus*

Test organisms	Zones of inhibition (mm)
Staphylococcus aureus	29.33±0.58
Bacillus subtilis	27.67±1.15
Escherichia coli (ATCC 25922)	26.33±0.58
Klebsiella pneumoniae (ATCC 3883)	19.33±0.58
Salmonella typhi	22.67±1.15
Candida albicans	4.67±0.58
Aspergillus flavus	9.33±0.58
Trichophyton mentagrophytes	26.67±0.58
Aspergillus niger	0.00±0.00
Microsporum canis	0.00±0.00

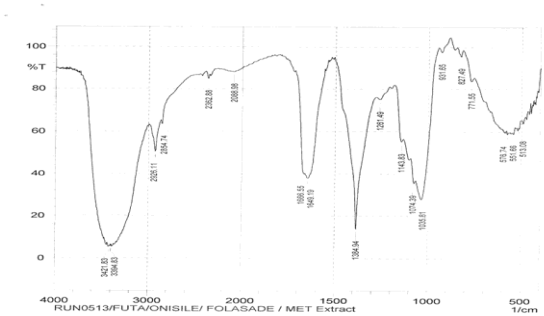


Figure 6: Infrared spectrum showing different peaks

Ekundayo and Faniomi (2017) characterised partially purified metabolite extract (PPME) from *Streptomyces collinus* ORFUTA (a strain isolated from soil at the Federal University of Technology, Akure) against different human and plant pathogens. The *S. collinus* PPME inhibited *Staphylococcus aureus* at 21.31 mm - larger than the inhibition zones produced by cotrimoxazole (0.00 mm, i.e. complete resistance), ceftriaxone (a third-generation cephalosporin, 18.90 mm), and ciprofloxacin (19.50 mm) (Table 10).

Table 10: Comparative antibacterial activities of partially purified *Streptomyces collinus* ORFUTA metabolite extract (PPME) with commercial antibiotics against selected human pathogens

Test Pathogen	*S. collinus* PPME (mm)	Cotrimoxazole (mm)	Ceftriaxone 3rd-gen (mm)	Ciprofloxacin (mm)
Staphylococcus aureus	21.31	0.00	18.90	19.50
Streptococcus pyogenes	18.50	0.00	17.20	18.00
Escherichia coli	16.80	0.00	15.60	17.10
Klebsiella pneumoniae	14.20	0.00	13.50	14.90

All measurements are zones of inhibition (mm) at 20 mg/ml extract concentration.

The MIC of the PPME against *Enterococcus faecalis* was 3.75 mg/ml, and against *Escherichia coli* was 7.50 mg/ml values competitive with early-generation clinical antibiotics. This finding positions *Streptomyces collinus* ORFUTA as a priority candidate for further purification, structural characterisation, and preclinical evaluation. The infrared spectrum of the antimicrobial agent showed bands corresponding to four peaks and these four peaks also denote four important functional groups revealing the hydroxyl group at 3390. The peak at 2080 showed the existence of alkane, carbonyl group at peak 1680 and the aromatic group at peak 1000.

The green synthesis of silver nanoparticles (AgNPs) using biological reducing agents (organisms or their extracts) represents one of the most rapidly expanding frontiers of applied microbiology globally, and it has attracted increasing attention within the Nigerian scientific community. My research has contributed to this field through studies demonstrating that microorganisms isolated from Nigerian soils can synthesise silver nanoparticles with antimicrobial activity superior, in some cases, to commercial antibiotics.

Ekundayo *et al.* (2021) investigated antimicrobial activities of silver nanoparticles AgNPs synthesized by rhizospheric and fishpond sediment microorganisms against selected clinical pathogens. The antibacterial activity of AgNPs synthesized by Gram-positive bacteria revealed that AgNPs from *B. subtilis* showed inhibition on *Enterococcus faecalis, Escherichia coli*, and *Staphylococcus aureus* respectively. The result of this research is in accordance with the findings of Deljou and Goudarzi (2015) who reported that AgNPs synthesized by *Bacillus* spp. showed significant inhibition on some selected human pathogens. The AgNPs synthesized from *S. aureus* showed significant inhibition on all the selected isolates except *K. pneumoniae*. The AgNPs synthesized by

M. luteus showed significant inhibition on *E. faecalis*, and *K. pneumoniae*. This research revealed that only *S. aureus* synthesized AgNPs showed inhibition on *Pseudomonas aeruginosa*. Antibacterial activity of Gram-negative-bacteria synthesized AgNPs revealed that *P. aeruginosa* synthesized AgNPs showed inhibition on all the selected isolates while E. coli-synthesized AgNPs showed inhibition on all the selected isolates except *P. aeruginosa*. The efficacy of AgNPs can be attributed to the fact that their larger surface area gives them a better contact with the microorganisms. The *A. niger*-synthesized AgNPs exerted antifungal effect on *R. stolonifer, P. notatum, A. flavus* and *T. viride* while it had activity against *A. fumigatus*. The *F. oxysporum* synthesized AgNPs exhibited antifungal activities against *T. viride, A. fumigatus, P. notatum* and *A. flavus* but no activity was exerted against *R. stolonifer*. The *S. cerevisiae*-synthesized AgNPs exhibited activity against *R. stolonifer, A. fumigatus* and *P. notatum* while no activity was shown against *A. flavus* and *T. viride*. The mode of action of AgNPs is triggered by the generation of reactive oxygen species (ROS) inside both bacterial and fungal cells. This study revealed that the microbially-synthesized AgNPs obtained from this study possessed a high antimicrobial potency against most potential pathogens investigated, and, thus, can be exploited in the development of novel antimicrobial.

Ekundayo *et al*. (2026) investigated the potential of *Bacillus* species from termitary (TMTR) and grassland soil (GRSL) samples to synthesise nanoparticles and their application in water purification. Findings from the study showed that nanoparticles were synthesised evident by the UV spectroscopy and FTIR and that the nanoparticles could reduce bacterial counts after 48 hours.

4.5 Other Microbial Biotechnology Dimensions

No career of genuine breadth is reducible to a single axis of inquiry. Alongside the four principal contributions presented above, this research has generated a set of contributions that, while individually distinct, collectively demonstrate the range of microbial biotechnology that evolved over twenty-five years. These include practical innovations in locally-sourced culture media, the microbial enhancement of indigenous food fermentation products; the antibacterial applications of plant extracts against waterborne coliforms and bioconversion of agro-industrial waste through cellulolytic enzymes from mushrooms.

Madam Vice Chancellor, **Ekundayo** and Ojokoh (2003) characterised microbial communities of fermented snake gourd and observed the effect of fermentation on its nutritional qualities. The results showed that fermentation increased the protein content of the endocarp. Also, **Ekundayo *et al.*** (2013) characterized the microbial communities responsible for the natural fermentation of *Irvingia gabonensis* seed cotyledons and documented the nutritional consequences of that fermentation process. *Bacillus cereus, B. subtilis, Penicillium chrysogenum, Aspergillus flavus* and *Trichoderma viride* were among the eleven organisms isolated. Fermentation increased crude protein from 0.54 to 2.25%, raised nitrogen-free extractives significantly, reduced phytate from 1.40 to 0.67, and reduced oxalate from 1.26 to 0.72 — transformations that collectively render the fermented seed a superior protein-rich food condiment with reduced antinutritional burden.

Ojokoh and **Ekundayo** (2005) identified that sweet potato (*Ipomoea batata*) infusion can serve as a functional substitute for imported potato dextrose agar in the cultivation of yeasts, including *Candida albicans, Saccharomyces cerevisiae, and Geotrichum candidum*.

Growth on sweet potato agar supplemented with 0.3% yeast extract was not merely comparable to PDA — it exceeded it for several yeast species. This work establishes the application of microbiology to reduce Nigeria's dependence on imported scientific consumables by exploiting what is abundantly available locally.

Abiola *et al.* (2010) investigated the antimicrobial efficacy of human saliva and its associated bacteria. Findings from the study revealed that the saliva inhibited the radial growth of *Phytophthora infestans* and *Rhiizoctonia solani* but was not antagonistic to *Aspergillus niger* and *Rhizopus* species. The study also showed that some of the human associated bacterial isolates were antagonistic to *P. infestans* and *R. solani.*

Ekundayo *et al*. (2011) examined the antimicrobial activity and phytochemical composition of pignut (*Jatropha curcas* Linn.) - a widely distributed indigenous plant used in traditional medicine across West Africa against pathogenic bacteria, using ethanol extracts of stem bark and leaves at 20 mg/ml concentration. Stem bark extracts produced inhibition zones of 30–38 mm against both Gram positive and Gram negative bacterial pathogens attributable to the phytochemical analysis showing alkaloids, tannins, saponins, flavonoids, and cardiac glycosides. These findings provide the scientific foundation for ethnomedicinal practices and establish *J. curcas* as a candidate for further phytochemical fractionation and bioactivity-guided isolation of active compounds.

Makanjuola *et al.* (2013) and **Dada *et al.*** (2014) examined the antibacterial potential of *Moringa oleifera* and *J. curcas* on coliforms from selected water samples. Our findings showed that aqueous extracts of *M. oleifera* and *J. curcas* demonstrated broad-spectrum activity against *Shigella dysenteriae, Salmonella typhi, Serratia marcescens, Enterobacter aerogenes, Escherichia coli,*

Citrobacter freundii, and *Proteus vulgaris*, with minimum inhibitory concentrations ranging from 3.00 to 7.00 mg/L — performance that compared favourably with the reference antibiotic gentamycin on most isolates. The chloroform fraction showed particularly high potency at low concentration. The studies point toward *M. oleifera* and *J. curcas* extracts as candidates for natural water-treatment agent for community-level application.

In **Ekundayo *et al.*** (2017), *Pleurotus ostreatus* and *P. pulmonarius*, cultivated on rice bran, corn cob, and sawdust under solid-state fermentation, were characterized for glucanase and β-glucosidase activity — the three cellulolytic enzyme classes required for lignocellulose degradation. Peak enzyme activity was consistently recorded on the ninth day of fermentation, after which activity declined as substrate was exhausted. *P. pulmonarius* on corn cob proved the superior endoglucanase and β-glucosidase producer, while *P. ostreatus* on rice bran excelled in exoglucanase activity. These findings established a potentially scalable platform for cellulolytic enzyme production using Nigeria's most abundant agro-industrial waste streams — corn cob from the grain belt, rice bran from the rice mills, and sawdust from the timber industry — all materials that currently represent disposal problems rather than biotechnology opportunities.

Bacillus subtilis isolated from stream sediments of Onyearugbulem Market in Akure was found to produce a bioflocculant (a microbially synthesised polymer capable of aggregating suspended particles in water) with optimal flocculating activity of approximately 90% at a dosage of 0.8 mg/ml (**Ekundayo *et al***., 2019). A comparative study demonstrated that the *B. subtilis* bioflocculant, combined with *M. oleifera* seed powder, reduced coliform counts in well water from 15.67 to 0.67 cfu/ml (a 95.7% reduction, which achieved

comparable or superior microbial removal to conventional alum treatment in stream and abattoir wastewater samples (Omiyale & **Ekundayo**, 2019). In a nation where access to safe drinking water remains compromised across millions of rural and peri-urban households, and where alum is imported and costly, locally produced bioflocculants derived from common soil bacteria represent a profoundly practical water treatment solution.

Madam Vice Chancellor, our research findings have immensely contributed to antimicrobial resistance (AMR) surveillance across four distinct environmental settings: clinical/environmental *Staphylococcus*, cultured *Clarias gariepinus*, hospital wastewater, and open dumpsites. **Ekundayo *et al.*** (2014) examined the composition, distribution, and antibiotic sensitivities of bacteria associated with cultured *C. gariepinus* (African catfish) at fingerling and adult stages, at the organs level (skin, gills, intestines) and from culture water and sediments. Fourteen bacterial genera were identified, predominantly Gram-negative rods including *Aeromonas, Alcaligenes, Chromobacterium, Citrobacter, Enterobacter, Escherichia, Klebsiella, Proteus, Pseudomonas, Salmonella,* and *Serratia*. Intestinal bacterial loads were 2 to 4 orders of magnitude higher than those of skin or culture water, confirming the gut as the primary microbial niche in fish and the site of most intensive antibiotic exposure in medicated aquaculture systems. Universal resistance to ampicillin was detected across all fish-associated bacterial isolates, while ciprofloxacin, perfloxacin, and gentamicin showed the highest efficacy.

Ogundare & **Ekundayo** (2015, 2016) isolated *S. aureus* from the hands of human subjects, and *S. epidermidis* isolated from unpolluted soil, were inoculated intradermally into healthy wistar albino rats, and the systemic and histological consequences were

monitored. Both organisms caused histopathological damage to lung, kidney, and liver tissues. Lung sections from the *S. epidermidis*-infected group (SSU) showed congestion, accumulation of erythrocytes between alveolar cells, haemorrhage, and necrosis. Kidney sections showed vacuolisation of the glomerulus, distruption of congested glomerular capillaries, and cell infiltration consistent with nephrotoxic injury. Liver sections showed cell vacuolation, ruptured veins, necrotic effects, and Kupffer cell infiltration. These findings confirm that environmental staphylococci possess pathogenic potential when they encounter a susceptible host through wound contamination, surgical exposure, or immune compromise. This finding has direct implications on patient safety.

Ogundare & E**kundayo** (2016) characterised the antibiotic resistance profiles of *Staphylococcus aureus* and *S. epidermidis* isolated from sources ranging from exposed tables and anatomical sites (ear, nose, throat, skin, hand) to environmental sites (polluted soil, cow dung, polluted water, unpolluted soil). Of 75 strains characterised, 50 were identified as *S. aureus* and 25 as *S. epidermidis.* The finding of universal resistance to pefloxacin, gentamicin, ampiclox, zinnacef, amoxicillin, rocephin, ciprofloxacin, streptomycin, and septrin across all 75 strains is alarming. The emergence of these resistance patterns outside clinical settings — in polluted soils, cow dung, and unpolluted environmental water — confirms that the environmental reservoir of resistance is not a secondary consequence of clinical antibiotic use, but an independent and self-perpetuating system of resistance maintenance and horizontal gene transfer. Isolates resistant to 10 to 13 antibiotics simultaneously were identified, representing the extreme end of the multiple antibiotic resistance (MAR) spectrum.

The most alarming single finding was the detection of vancomycin resistance in 18.2% of environmental *Streptococcus* isolates (**Ekundayo *et al***., 2016). Vancomycin is the antibiotic of last resort for Gram-positive bacterial infections including MRSA. The detection of vancomycin-resistant enterococci (VRE) and related organisms outside clinical settings (in the ambient Nigerian environment) is a sentinel event that demands immediate attention from public health authorities, infection control practitioners, and environmental regulators.

Olotu *et al.* (2020) studied microbial populations in the sediments of three rivers in Ondo State — the Ala, Ogbese, and Owena rivers. Total aerobic bacterial populations were highest at the surface (0 cm) across all three rivers, while anaerobic bacteria predominated at 100 and 150 cm depths. The conductivity and salinity measurements across rivers and depths revealed that the Ala River had the highest ionic content at the water surface (conductivity: 750 µS; salinity: 360 ppm), reflecting its proximity to urban discharge points and agricultural run-off. The microorganisms common to all the river sediments of the three rivers were *Pseudomonas aeruginosa, Salmonella* sp, *Escherichia coli, Penicillium notatum, Aspergillus niger, and Rhizopus* sp. this finding connects the aquatic ecology data to the broader narrative of anthropogenic environmental degradation.

Hospital wastewater is one of the most concentrated environmental reservoirs of antimicrobial resistance. **Usman *et al.*** (2021a, 2021b, 2021c) characterised the antibiotic sensitivity profiles of bacteria isolated from hospital wastewater in both wet and dry seasons. Five antibiotics; ceftazidine, cefuroxime, cloxacillin, augmentin, and cefixime showed 100% resistance in both wet and dry seasons among hospital wastewater isolates. Only ofloxacin and gentamicin

retained significant efficacy, and both are antibiotics whose use is already constrained by toxicity concerns. The seasonal comparison revealed that dry-season isolates were, in some respects, more resistant than wet-season isolates - a finding consistent with the hypothesis that reduced dilution effects during dry season led to higher effective antibiotic concentrations in the wastewater stream, imposing stronger selection pressure for resistance.

Ekundayo *et al*. (2025) assessed the bacteriological quality of soil samples from open dumpsites in Ondo City, Ondo State - sites that are characteristic of urban and peri-urban Nigeria and that are used by millions of residents as the primary means of solid waste disposal. The genera isolated from these five dumpsite locations included *Bacillus, Klebsiella, Escherichia, Pseudomonas, Clostridium, Staphylococcus,* and *Salmonella*. Antibiotic susceptibility testing revealed high resistance to norfloxacin, ampiclox, and chloramphenicol in *S. aureus*, and high resistance to nalidixic acid, ampicillin, and ofloxacin in *Klebsiella pneumoniae*. The MAR index for *K. pneumoniae* reached 0.7 — indicating resistance to 70% of the antibiotics tested, a value that qualifies these isolates as highly multidrug-resistant by international classification criteria. The proximity of these dumpsites to residential areas, children's play spaces, urban farms, and water abstraction points makes this finding a direct public health emergency.

Madam Vice Chancellor, **Olotu *et al.*** (2019) investigated electricity generation from river sediment microbial communities using microbial fuel cells (MFCs). A double-chamber MFC was constructed using mud sediment collected from six depths (water surface, 0 cm, 50 cm, 100 cm, and 150 cm) from River Ogbese in Ondo State. Anaerobic conditions were maintained in the anode chamber, with aerobic conditions in the cathode chamber, connected

by a salt bridge of 3% agar in 1M NaCl. Voltage, current, power, and current density were measured using a multimeter. The experiment generated measurable electrical output: peak voltage readings of approximately 800 mV were recorded. — a value that challenges the audience's intuition about what river mud can achieve. Peak power output was approximately 0.24 W. Our findings showed that indigenous anaerobic microbial communities of River Ogbese were capable of generating bioelectricity through electron-transfer reactions in a fuel cell configuration.

5.0 CONCLUSION

This lecture has traversed a quarter of a century of scientific enquiry — from the validation of sweet potato agar in the earliest years of a teaching career, through the systematic mapping of Nigeria's rhizosphere microbiology, to the demonstration that river mud generates electricity and that nanoparticles synthesized by soil bacteria are more potent than clinical antibiotics.

The studies have shown what Nigeria's native microbial communities can do for Nigeria's people. The findings, taken together, constitute a coherent and practically significant body of knowledge. They established that the safe operating window for benomyl in cowpea cultivation is 0.10–0.20 g/ml — above this, the nitrogen-fixing symbiosis that sustains cowpea as a protein crop collapses.

They demonstrated that *T. viride* from abattoir soil suppressed *S. rolfsii* at 88% efficiency in acid tropical soils — a performance that justifies commercial development. They confirmed that *P. ostreatus* reduced crude oil contamination by more than 90% in six months — but that its counterpart *P. pulmonarius* accumulated toxins that damage mammalian organs.

They revealed that bacteria in selected hospital wastewater already resisted five classes of clinically critical antibiotics, and that open dumpsites were functional AMR reservoirs in residential communities. They demonstrated that *S. collinus* isolated from FUTA soil outperformed commercial antibiotics against resistant *Staphylococcus aureus*.

Finally, our results have shown that anaerobic bacteria in an Ondo State River can generate measurable bioelectricity in a microbial fuel cell for the first time in this region.

5.1 Future Directions

Madam Vice Chancellor, an inaugural lecture that only summarises research findings would be an incomplete scholarly statement without stating future research directions.

In agricultural microbiology, our priority is the formulation and multi-location field testing of commercial biofertilizer. Collaboration with the International Institute of Tropical Agriculture (IITA) Ibadan and the National Agricultural Seeds Council will be developed to provide the field trial infrastructure needed for regulatory approval.

In bioremediation, the priority is the transition from pot-scale to pilot-field-scale *Pleurotus ostreatus* mycoremediation at a representative Niger Delta crude oil spill site, in collaboration with HYPREP and appropriate oil company partners. This will require the development of a standardised inoculation protocol, a TPH monitoring programme, and a community engagement process with affected farming households - including explicit protocols for preventing the consumption of fruiting bodies from remediation plots, based on the safety assessment findings reviewed.

In drug discovery, the programme proposes to take *Streptomyces* species isolated from soil samples through the complete natural products pipeline: preparative HPLC isolation of the active fraction, structural elucidation by NMR spectroscopy and mass spectrometry, determination of minimum inhibitory concentrations against a panel of multidrug-resistant clinical isolates, cytotoxicity screening in human cell lines, and — if the preclinical profile is favourable — engagement with the National Institute for Pharmaceutical Research and Development (NIPRD) for the Investigational New Drug pathway.

In nanotechnology, the programme will pursue the optimisation of silver nanoparticle synthesis from the programme's most productive organisms, toxicological characterisation in mammalian cell lines and zebrafish embryo models, and evaluation of synergistic antibacterial activity in combination with conventional antibiotics.

5.2 A Closing Reflection

Findings from our research carry real human consequences. The cowpea farmer over-applying benomyl destroys the nitrogen fixing bacteria feeding his family. The hospital personnel discharging untreated effluent exports drug-resistant bacteria to neighbours. The child playing on the open dumpsite is exposed to *Klebsiella pneumoniae* resisting 70% of available antibiotics. Microbiology is the science of the invisible. This lecture has made visible what lies beneath Nigeria's farms, rivers, hospitals, and dumpsites. The obligation to act on that visibility (translating knowledge into policy and laboratory findings into technologies that reach the farmer, the patient, and the regulator) belongs not only to the microbiologist, but to every institution with the power to convert science into action.

Beneath every Nigerian farm, microbial life works ceaselessly. This inaugural lecture has summarized my research output for the past twenty-five years. It is also an invitation (to colleagues, students, policymakers, the Vice-Chancellor, and the Senate) to consider what it might yet produce for this nation and continent, if scientific vigilance is sustained, policy response is adequate, and institutional will is present.

6.0 RECOMMENDATIONS

Science that does not speak to policy is incomplete. Our research findings reviewed in this lecture have direct implications for agricultural management, environmental regulation, public health policy, and biotechnology development in Nigeria. Madam Vice Chancellor, I wish to make the following recommendations:

i. **Agrochemical Guidelines -** Benomyl was safe for cowpea rhizobia at 0.10–0.20 g/ml but caused 94.3% nodule destruction at 0.80 g/ml; these thresholds, plus species-specific resilience data for atrazine, glyphosate, and insecticides, should be formally incorporated into extension guidelines.
ii. **Biofertilizer Development** - *Trichoderma viride*, *Bacillus subtilis*, and *Proteus mirabilis* are priority candidates for commercial inoculants; NIAR and IITA should advance them from laboratory to shelf-stable, field-tested products.
iii. **Biocontrol Commercialisation -** *T. viride* (88% inhibition of *S. rolfsii*), *B. subtilis* (89% inhibition of *F. solani*), and *P. pseudomallei* (60% inhibition of *S. rolfsii*) warrant FUTA-funded multi-location field trials.
iv. **Fermentation Promotion -** Bush mango fermentation yielded a 316% crude protein increase with reduced antinutrients; the Federal Ministry of Agriculture should disseminate these protocols through extension services, especially to women's cooperatives in South-West and South-South Nigeria.

v. **Mycoremediation -** *P. ostreatus* achieved >90% TPH reduction in six months at low cost. Hydrocarbon Pollution Remediation Project (HYPREP), National Oil Spill Detection and Remediation Agency (NOSDRA) and oil companies should adopt it as a primary remediation technology, supported by standardised protocols and site-safety certification.

vi. **Mushroom Consumption Ban -** *P. pulmonarius* grown on contaminated soil caused organ histopathology in mammals; regulations must prohibit harvesting mushrooms from active or recently remediated plots.

vii. **Hospital Effluent Treatment -**With 100% resistance across five antibiotic classes in hospital wastewater isolates, National Environmental Standards and Regulations Enforcement Agency (NESREA) should mandate tertiary biological treatment and UV disinfection for all hospitals exceeding 50 beds.

viii. **Dumpsite Closure -** *K. pneumoniae* MAR indices of 0.7 in Ondo City dumpsites confirmed that they are residential AMR reservoirs; Federal, State, and LGA authorities must replace open dumpsites with engineered sanitary landfills.

ix. **One Health AMR Surveillance -** Resistance reservoirs across hospitals, fish farms, soils, and dumpsites are interconnected; a nationally funded One Health AMR framework is urgently needed, with Department of Microbiology, FUTA as a regional reference laboratory.

x. **Aquaculture Antibiotic Regulation** - Universal ampicillin resistance in cultured catfish confirms farms are AMR amplifiers; the Federal Department of Fisheries and National Veterinary Research Institute (NVRI) should enforce mandatory treatment records, ban growth-promotion antibiotics, and require sensitivity testing before therapy.

xi. ***Streptomyces*** **Drug Discovery** - *S. collinus* ORFUTA metabolite outperformed cotrimoxazole and matched third-generation cephalosporins; Nigeria should establish a National Natural Products Drug Discovery Programme to advance such

metabolites through structural, mechanistic, and pre-clinical studies.

xii. **Sweet Potato Agar Standardisation -** The Federal Ministry of Science and Standard Organisation Nigeria (SON) should formally standardise sweet potato agar as a PDA substitute, cutting foreign exchange costs and broadening research capacity.

xiii. **Microbial Fuel Cell Investment-** River Ogbese MFC data provide proof of concept for distributed rural energy generation; TETFund and NASENI should co-fund a multi-institution, multi-river MFC optimisation programme.

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REFERENCES

Abiola, O. F., Ekundayo, E. A., Adetuyi, F. C. & **Ekundayo, F. O.** (2010). *In vitro* antimicrobial potentials of human saliva-borne bacteria. Conference proceedings, 2nd International Biennial conference, Faculty of Science, Adekunle Ajasin University, Akungba-Akoko, Ondo State. Pp 118 – 123

Agboola, A. A**., Ekundayo, F. O**., Ekundayo, E. A., Fasoro, A. A., Ayantola, K. J. & Kayode, A. J. (2018). Influence of glyphosate on rhizosphere microorganisms and their ability to solubilise phosphate. *Journal of Microbiology and Antimicrobial Agents*, 4(2): 15–21. ISSN 2396-880X.

Akobundu, I. O. (1987). Herbicides in the Environment: Weed Science in the Tropics — Principles and Practices. Wiley-Interscience, pp. 179–206.

Araújo, A. D., Monteiro, R. T.R. & Abarkeli, R. B. (2003). Effect of glyphosate on the microbial activity of two Brazilian soils. *Chemosphere*, 52(5): 799–804.

Bardgett, R. D. & van der Putten, W. H. (2014). Belowground biodiversity and ecosystem functioning. *Nature*, 515: 505–511.

Behbahani, M. & Behbahani, M. (2009). Investigation of biological behaviour of Iranian indigenous phosphate solubilising bacteria and determinant of colonisation ability of potato roots by the bacterial isolation. *Journal of Medicinal Plants Research*, 3(12): 1126–1133.

Cervelli, S., Nannipieri, P. & Sequi, P. (1978). Interactions between agrochemicals and soil enzymes. In: Soil Enzymes. Academic Press, pp. 251–293.

Chet, I., Inbar, J. & Hadar, I. (2007). Fungal antagonists and mycoparasites. In: The Mycota IV — Environmental and Microbial Relationships. Springer, pp. 165–184.

Chutrakul, C., Almagro, L., Bonfill, M. & Pedreño, M. A. (2008). Trichoderma secondary metabolites. *Phytochemistry*, 69: 324–331.

Dada, E. O., Makanjuola, O. O. and **Ekundayo, F. O.** (2014). Antibacterial activities of *Jatropha curcas* (LINN) on coliforms isolated from

some surface waters in Akure. *International Journal of Biomedical Science*, 10(1): 25 – 30.

Ekundayo, E. A., Olubunmi, B. G., Kone, J. K., **Ekundayo, F. O**., Abayomi, D. T. & Adewoyin, H. O. (2025). Bacteriological assessment of soil samples collected from some selected dump sites in Ondo Metropolis, Ondo State, Nigeria. *FUTA Journal of Life Sciences*, 5(1): 182–192.

Ekundayo, F. O. (2010). Comparative influence of benomyl on rhizosphere and non-rhizosphere bacteria of cowpea and their ability to solubilise phosphate. *Journal of Soil Science and Environmental Management*, 1(9): 234–242.

Ekundayo, F. O. (2014). Bioremediation of crude oil and engine oil contaminated soil using *Pleurotus ostreatus* and *Pleurotus pulmonarius*. *Advances in Microbiology*, 4: 849–855.

Ekundayo, F. O., Adeboye, C. A. & Ekundayo, E. A. (2011). Antimicrobial activities and phytochemical screening of pignut (*Jatropha curcas* Linn.) on some pathogenic bacteria. *Journal of Medicinal Plants Research*, 5(8): 1261–1267.

Ekundayo, F. O., Adegunloye, D. V. & Oyewumi, O. O. (2024). Physicochemical Properties Before and After Bioremediation of Crude Oil Polluted Soils from Ilaje, Ondo State, Nigeria. *Journal of Applied Science and Environmental Management*, 28 (10B Supplementary): 3265-3271.

Ekundayo, F. O., Adeyanju, A. O. and Ekundayo, E. A. (2026). Investigating *Bacillus*-producing nanoparticles as alternatives to conventional flocculants and disinfectants in water purification. *Journal of Applied Science and Environmental Management* **(Accepted)**

Ekundayo, F. O. & Alaofin, S. (2019). Biocontrol potential of *Pseudomonas* species isolated from benomyl-treated rhizosphere soil. *American Institute of Science*, 153–158.

Ekundayo, F. O., Diyaolu, D. O. & Fasakin, E. A. (2014). Composition, distribution and antibiotic sensitivities of bacteria associated with cultured *Clarias gariepinus* (Burchell 1822). *Malaysian Journal of Microbiology*, 10(2): 72–79.

Ekundayo, F. O., Ekundayo, E. A. & Bamidele, F. (2016). Chitinase production by *Aspergillus nidulans* isolated from rhizosphere of fruit trees. *Mycosphere*, 7(6): 786–793.

Ekundayo, F. O., Ekundayo, E. A., Omoyeni, B. O. & Osibote, I. A. (2014). Biodegradation of petroleum products by *Bacillus* species. *Egyptian Academic Journal of Biological Sciences*, 6(1): 91–97.

Ekundayo, F. O., Ekundayo, E. A. & Salami, A. A. (2018). Effect of some environmental conditions on the growth of *Rhizobium* species. *Journal of Biological Sciences*, 26: 15–24.

Ekundayo, F. O. & Faniomi, A. S. (2017). Antimicrobial activity of partially purified metabolite extract of *Streptomyces collinus* ORFUTA against selected pathogens. *Asian Journal of Medical and Health Research*. DOI: 10.9734/AJMAH/2017/30407.

Ekundayo, F. O., Folorunsho, A.E., Ibisanmi, T. A. and Olabanji, O. B. (2022). Biosynthesis of silver nanoparticles and antifungal activity of chitinase from *Streptomyces albus. Bulletin of the National Research Centre*, 46: 95.

Ekundayo, F. O. and Ojokoh, A. O. (2003). Effects of fermentation and spoilage on the proximate composition and nutrient value of snake guard. *Proceedings of 16th Annual Conference of Biotechnology Society of Nigeria*. Pp 105 – 108.

Ekundayo, F. O. & Oladunmoye, M. K. (2007). Influence of benomyl on ability of *Fusarium oxysporum* and *Fusarium solani* to produce beauvericin and rhizosphere organisms of cowpea. *International Journal of Soil Science*, 2(2): 135–141.

Ekundayo, F. O., Oladipupo, O. A. and Ekundayo, E. A. (2013). Studies on the effects of microbial fermentation on bush mango (*Irvingia gabonensis*) seed cotyledons. *African Journal of Microbiology Research*, 7(34): 4363 – 4367.

Ekundayo, F. O., Olukunle, O. F. & Ekundayo, E. A. (2012). Biodegradation of Bonny light crude oil by *Pseudomonas fluorescens* and other fungi isolated from polluted soil. *Malaysian Journal of Microbiology*, 8(1): 42–46.

Ekundayo, F. O., Omiyale, F. B. & Omomo, E. R. (2019). Flocculating properties of a bioflocculant purified from *Bacillus subtilis* isolated

from the stream sediments of Onyearugbulem Market, Akure, Nigeria. *Microbiology Research Journal International*, 28(5): 1–16.

Ekundayo, F. O. & Osunla, C.A. (2013). Phytase production by fungi isolated from contaminated and uncontaminated soils. *African Journal of Biotechnology*, 12(36): 5540–5548.

Etok, C. A., Asamudo, N. U., Onwuchekwa, I. S. & Nwaugo, V. O. (2010). Effects of quarry plant rock dusts on soil phosphate solubilising bacteria and enzyme activities in Ishiagu, Ebonyi State, Nigeria. *Nigerian Journal of Microbiology*, 24(1): 2207–2213.

Halder, A. K., Mishra, A. K., Bhattacharyya, P. & Chakrabartty, P.K. (1990). Solubilisation of rock phosphate by *Rhizobium* and *Bradyrhizobium. Journal of General and Applied Microbiology*, 36(2): 81–92.

Kremer, R. J. & Means, N. E. (2009). Glyphosate and glyphosate-resistant crop interactions with rhizosphere microorganisms. *European Journal of Agronomy*, 31(3): 153–161.

Lacerda, A. M., Moreira, F. M. S., Andrade, M. J. B. & Soares, A. L. L. (2004). Yield and nodulation of cowpea inoculated with selected strains. *Revista Ceres*, 51: 67–82.

Liu, C. M., McLean, P. A., Sookdeo, C. C. & Cannon, F. C. (1991). Degradation of the herbicide glyphosate by members of the family Rhizobiaceae. *Applied and Environmental Microbiology*, 57(6): 1799–1804.

Makanjuola, O. O., Dada, O. E. and **Ekundayo, F. O.** (2013). Antibacterial activities of *Moringa oleifera* (LAM) on coliforms isolated from some surface waters in Akure. *FUTA Journal of Research in Sciences*, 1: 63-71.

Mitchell, P. (1999). Oil spill statistics. Oil Spill Intelligence Reports.

Neumann, G., Kohls, S., Landsberg, E., Stock-Oliveira, S. K., Yamada, T. & Römheld, V. (2006). Relevance of glyphosate transfer to non-target plants via the rhizosphere. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz-Sonderheft, 20: 963.

Newsham, K. K., Fitter, A. H. & Watkinson, A. R. (1994). Root pathogenic and arbuscular mycorrhizal fungi determine fecundity of an asymptomatic plant in the field. *Journal of Ecology*, 82: 805–814.

Ogundare, A. O. & **Ekundayo, F. O.** (2016). Antibiogram of *Staphylococcus aureus* and *Staphylococcus epidermidis* from various sources in Ondo State, Nigeria. *Journal of Advances in Biology and Biotechnology*, 10(2): 1–13.

Ogunsakin, O. A., Ekundayo, E. A., **Ekundayo, F. O.** & Olalemi, O. A. (2024). Green synthesis of silver nanoparticles using *Penicillium digitatum. Journal of Biological Sciences*, 32(2): 31–44.

Ojokoh, A. O. & **Ekundayo, F. O.** (2005). Evaluation of the performance of sweet potato infusion as a medium for culturing yeasts. *Journal of Food Technology*, 3(3): 440–443.

Oladapo, B. O., Ekundayo, E. A., Mokoolu, M. O. & **Ekundayo, F. O.** (2020). Phosphate solubilisation potentials of rhizosphere fungi isolated from insecticide treated soil. *Advanced Research in Life Sciences*, 4: 58–69.

Oladapo, B. O., Ekundayo, E. A., **Ekundayo, F. O.** & Gbaye, O. A. (2021). Effect of lambda-cyhalothrin and dimethoate on the growth response of cowpea plants and the surrounding soil. *Annals of Science and Technology*, 6(2): 1–13.

Olotu, T. M., Adegunloye, D. V. & **Ekundayo, F. O.** (2019). Power generation through double chamber MFC operation using various depths of mud sediment from River Ogbese. International *Journal of Innovative Research in Science, Engineering and Technology*, 8(4): 4394–4401.

Olotu, T. M., Adegunloye, D. V., **Ekundayo, F. O.,** Ojo A. F, Agunloye, O. G., Ajibade, O. A· & Amao, F. A. (2020). Microbial populations in sediments of Ala, Ogbese and Owena rivers at various depths. *International Journal of Applied Science and Research*, 3(3): 88-100.

Omiyale, F. B. & **Ekundayo, F. O**. (2019). Comparative effects of conventional and non-conventional flocculants and disinfectants on microbial contaminants in water purification. *Journal of Advances in Microbiology*, 18(3): 1–15.

Omokaro, D. N. & Ajakaiye, C. O. (1989). Effects of soil-applied herbicides on leaf nitrate reductase and crude protein in the leaf and seed of two cowpea cultivars. *Plant and Soil*, 116(2): 141–146.

Onifade, A. K., Abubakar, F. A. & **Ekundayo, F. O.** (2007). Bioremediation of crude oil polluted soil in the Niger Delta area of Nigeria using enhanced natural attenuation. *Research Journal of Applied Sciences*, 2(4): 498–504.

Onifade, I. A., Orisadipe, D. B., Nkor, N. D., **Ekundayo, F. O.** and & Arogunjo, A. O. (2021). Biodegradation of crude oil by bacteria isolated from orange, teak, and cocoa plants. *Asian Journal of Biology and Biotechnology, 7(4): 87–92.*

Oyewumi, O. O., **Ekundayo, F. O.** & Adegunloye, D. V. (2024). Biosynthesis of silver nanoparticles by bacteria isolated from crude-oil-polluted soil. *FUTA Journal of Life Sciences.*

Peacock, T. J., Mikell, A. T. & Smith, J. R. S. (2014). Application of a redox gradostat reactor for assessing rhizosphere microorganism activity on lambda-cyhalothrin. *Bulletin of Environmental Contamination Toxicology*, 92: 347–351.

Pozo, C., Martinez-Toledo, M. V., Salmeron, V., Rodelas, B. & Gonzalez-Lopez, J. (1995). Effect of chlorpyrifos on soil microbial activity. *Environmental Toxicology and Chemistry*, 14: 187–192.

Saha, N. & Biswas, S. (2009). Mineral phosphate solubilising bacterial community in agro-ecosystems. *African Journal of Biotechnology*, 8(24): 6863–6870.

Santos, J. B., Jacques, R. J. S., Procópio, S. O., Kasuya, M. C. M., Silva, A. A. & Santos, E. A. (2004). Effects of different glyphosate commercial formulations on *Bradyrhizobium* strains. *Planta Daninha*, 22(2): 293–299.

Singh, B., Kaur, R. & Singh, K. (2008). Characterisation of Rhizobium strain isolated from the roots of *Trigonella foenum-graecum* (fenugreek). *African Journal of Biotechnology*, 7(20): 3671–3676.

Susilowati, A. & Wiyono, S. (2011). Potential of *Pseudomonas* isolated from soybean rhizosphere as biocontrol against soil borne phytopathogenic fungi. *HAYATI Journal of Biosciences*, 18 (20): 51-56.

Usman, K. M., Arotupin, D. J. & **Ekundayo, F. O.** (2021a). Characterisation of bacteria isolated from hospital wastewater. *African Journal of Microbiology Research*, 15(11): 572–582.

Usman, K. M., Arotupin, D. J. & **Ekundayo, F. O.** (2021b). Appraisal on microbiological qualities of wastewaters from Offa Local Government Area of Kwara State, Nigeria. *Journal of Advances in Microbiology*, 21(9): 25–38.

Usman, K. M., Arotupin, D. J. & **Ekundayo, F. O.** (2021c). Antibiotic susceptibility pattern of hospital wastewaters' bacteria from Oyun Local Government Area of Kwara State, Nigeria. *International Journal of Scientific Engineering and Applied Science*, 7(11): 136 – 151

Weaver, M. A., Krutz, L. J., Zablotowicz, R. M. & Reddy, K. N. (2007). Effects of glyphosate on soil microbial communities and its mineralisation in a Mississippi soil. *Pest Management Science*, 63(4): 388–393.

World Health Organisation (2021). Antibacterial agents in clinical and preclinical development: an overview and analysis. WHO, Geneva.

Zhang, G., Jia, X., Cheng, T., Ma, X. & Zhao, Y. (2005). Isolation and characterisation of a new carbendazim-degrading *Ralstonia* sp. strain. *World Journal of Microbiology and Biotechnology*, 21: 265–269.