UNIVERSITY OF ILORIN

THE TWO HUNDRED AND SIXTY-FIRST (261ST) INAUGURAL LECTURE

"MICROORGANISMS IN THE SERVICE OF MAN"

By

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My Lords Spiritual and Temporal,
Esteemed Invited Guests,
Members of the Print and Electronic Media,
Great students of the University of Ilorin,
Distinguished Ladies and Gentlemen.

Preamble

Vice-Chancellor sir, it is with gratitude to God that I stand before this distinguished audience to present the 261st inaugural lecture of the University of Ilorin. The journey so far has been only by the grace of God. Whatever I have achieved, it has been by His mercy and to Him I return all the glory and honour, forever and ever, amen. This inaugural lecture is the 10th from the Faculty of Life Sciences, and the 2nd from the Department of Microbiology that was carved out of the defunct Department of Biological Sciences in 2014. It is the 1st from the Food and Industrial Microbiology unit, and the 1st by a female academic in the Department.

My being a microbiologist today has been by divine arrangement. This is because I did not initially set out to become a microbiologist as I had no idea who microbiologists were. Like many young science students, I wanted to become a medical doctor or at the very least a pharmacist. However, I accepted the admission offer into Department of Biological Sciences, University of Ilorin, where the practice was to stream students to Botany, Microbiology or Zoology as a specialized discipline at the final year. As God would have it, I was streamed to Microbiology and graduated with a B.Sc. (Hons.) degree in Microbiology in 1986. After my graduation, my parents brought up my old dream of studying medicine, and asked if I wanted to apply for medicine through Direct Entry, but by then, the dream had died and I had 'buried' it as I had begun to envision my future in Microbiology. With the benefit of hindsight, I have no regrets whatsoever not being a Medical Doctor (MD), as I am a proud Microbiology Doctor (MD) and a Professor of Microbiology by divine providence.

I consider myself a veritable product of my *alma mater* and a major stakeholder in the University of Ilorin project. I have earned all my degrees: B.Sc. (Hons.) 1986; M.Sc. (1989) and Ph.D. in 1992 from the prestigious University of Ilorin. In addition, I have had the privilege of contributing to its growth and development over the past two and a half decades by dedicating my entire productive life to it.

Introduction

Vice-Chancellor sir, this inaugural lecture titled **Microorganisms in the Service of Man** chronicles my odyssey in researching the roles played by microorganisms in biodegradation, fermentation, food preservation and waste value addition.

Microbiology and Microorganisms

Microbiology is the study of microorganisms, which are tiny organisms that are invisible to the naked eye. They are viewed with the aid of a microscope. These microorganisms include bacteria, viruses, fungi, protozoa, and microscopic algae. Microbiologists study these organisms to understand their structure, function, metabolism, interactions with other organisms, and their roles in various ecosystems, including their impact on human health, agriculture, industry, and the environment.

Microbiology encompasses various sub-disciplines, such as industrial microbiology (using microorganisms for commercial purposes like food production, biotechnology, and biofuel production), medical microbiology (that focused on the study of microorganisms which cause diseases in humans), environmental microbiology (studying microorganisms in natural and built environments), and microbial genetics (examining the genetics and molecular biology of microorganisms). Microbiology has various applications in the fields of medicine, agriculture, biotechnology, environmental science, and others.

Microorganisms are infamous for being responsible for many damaging and deleterious interactions in nature. Some of such incidences, amidst numerous ones, are the very popular epidemics and pandemics of global concern, e.g. the Black Death in the 14^{th} century that killed between 75-200 million people, the Spanish flu (1918-1919) which infected about one-third of the global population and killed about 50 million, and more recently, the on-going corona virus (COVID-19) pandemic (2019- date) which has affected nearly all the countries of the world and has killed about 14.9 million people (WHO, 2022).Other negative microbial activities are food spoilage; environmental degradation and destruction of materials; all these leading to enormous human and material as well as significant economic losses.

Microorganisms though often associated with diseases, however play vital and beneficial roles in various aspects of human life and have many valuable uses that can be harnessed in the service of man which include: the production of vitamins, antibiotics, vaccines and other pharmaceuticals for food production, preservation, detoxification, and flavour development through fermentation. The use as probiotics to improve gut health; enhancement of soil fertility, plant health and nutrient recycling; degradation of pollutants in air, water and soil through bioremediation; treatment of sewage and wastewater in water recycling for irrigation. Microorganisms are used in various biotechnological applications, including enzyme production, bioprocessing, and genetic engineering. Enzymes produced by microorganisms are used in industrial processes such as laundry detergents, biofuel production, and pharmaceutical manufacturing. Microorganisms like *Escherichia coli* and *Saccharomyces cerevisiae* are commonly used as host organisms for the production of recombinant proteins and bio-based chemicals. These are just a few examples of the beneficial uses of microorganisms, highlighting their importance in diverse fields and industries.

Microbiology has evolved from the 17th century when the pioneers such as Antonie van Leeuwenhoek (1632-1723) and Robert Hooke (1635-1703) developed the first crude microscope to view microorganisms which they called *animalcules*(meaning "small animals") to the 21st century where advances in sequencing technologies and bioinformatics have facilitated large-scale studies of microbial diversity, evolution, and community dynamics. Microbiology research has developed, leading to a deeper understanding of the microbial communities that inhabit diverse environments, including the human body. Current research approaches have enabled the design and engineering of novel microbial systems for various applications, including bioremediation, biofuel production, and medical therapies. Overall, microorganisms, often invisible to the naked eye, have profound and positive impacts on human life. Through their diverse applications, they enhance health, boost agricultural productivity, drive industrial innovation, and support environmental sustainability. These are part of the roles of **microorganisms in the service of man**.

Food and Industrial Microorganisms and their Useful Products

Vice-Chancellor sir, certain microorganisms classified as food microorganisms, plays numerous beneficial roles in food production and processing, contributing to both the creation of foods and enhancing their safety, flavour, and nutritional value. While some others, in the course of their normal metabolism, produce metabolites of industrial importance, and these have been designated as industrial microorganisms. They are utilised in various industrial processes for the production of valuable products or for carrying out specific biochemical transformations. These microorganisms are typically selected or engineered for their ability to efficiently produce desired metabolites or perform specific tasks under industrial conditions. They include members mostly from bacteria and fungi.

1. **Bacteria**

Various bacterial species are useful in various production processes. Notable examples include:

a. *Escherichia coli:* used in biotechnology for the production of therapeutic proteins, enzymes, and other useful metabolites through recombinant DNA technology. Recombinant DNA technology also known as genetic engineering has a wide range of applications such as gene therapy, vaccine development, gene cloning and expression, production of biopharmaceuticals, biosensors and biofuels.

b. *Bacillus:* used for their ability to produce enzymes such as amylases, proteases, and lipases which are used for various industrial processes, including food processing, and detergent manufacturing.

c. *Clostridium*: used in industrial fermentation processes for the biological production of solvents such as acetone, butanol, and ethanol; biofuels such as butanol; industrial enzymes e.g. cellulases and hemicellulases; biopolymers such as bioplastics which are biodegradable, bioremediation of certain polluted environments; and sewage treatments with the production of biogas.

d. *Lactic Acid Bacteria*: a group of Gram-positive, non-spore forming bacteria that produce lactic acid as their major end product of carbohydrate metabolism. They are commonly found in various natural environments, including plants, animals, and fermented foods. Lactic acid bacteria have been extensively studied and utilised for their beneficial roles in food fermentation, probiotics, and biopreservation. Members of this group are mainly from the genera: *Lactobacillus, Streptococcus, Leuconostoc*, *Lactococcus, Pediococcus, Bifidobacterium, Enterococcus, Aerococcus* and *Carnobacterium*. They are involved in the production of fermented dairy products, probiotics, organic acids, bacteriocins and hydrogen peroxide.

2. **Fungi**

These are a diverse group of microorganisms that are highly synthetic in nature and are utilised in several industrial processes. Some are unicellular called yeasts, while the filamentous forms are called moulds. Fungi are widely distributed in nature and occur in diverse habitats. Yeasts play important roles in various ecological processes, particularly in fermentation, where they convert sugars into alcohol and carbon dioxide. They are used in the production of alcoholic beverages such as beer, wines and spirits. Yeasts are widely employed in biotechnological applications, particularly in the production of enzymes and recombinant proteins. Yeasts are used in the production of biofuels such as ethanol and biodiesel. Industrially important yeasts are mainly from the genera *Saccharomyces, Candida, Pichia, Kluyveromyces* and *Debaryomyces.* Of particular note is the most studied and versatile yeast; *Saccharomyces cerevisiae,* which has great economic importance in the baking, brewing, wine-making, and biofuel production. Moulds are noted for their ability to produce different enzymes and other valuable metabolites. They include *Aspergillus* known for their ability to produce enzymes such as amylases, cellulases, and proteases used in various industrial processes, including food processing and biofuel production; *Penicillium* used in the production of antibiotics such as penicillin and cephalosporins; *Trichoderma* and *Fusarium* used for the production of cellulases and hemicellulases for biomass conversion.

3. **Algae**

Certain microalgae species have been utilised for their potential in industrial applications such as biofuel production, wastewater treatment, and the production of high-value compounds such as omega-3 fatty acids which confer various health benefits, including improving cardiovascular health, brain function, and inflammation regulation. Algae are also involved in the production of pigments such as chlorophyll, phycocyanin, zeaxanthin, astaxanthin and beta-carotene which are used as natural food colourings and also possess antioxidant properties. Such algae include *Chlorella, Spirulina, Nannochloropsis, Schizochytrium*, *Ulkenia* and *Dunaliella.*

These are just a few examples of the diverse range of microorganisms used in food and industrial processes. Industrial microorganisms are often selected or engineered based on their ability to efficiently produce desired products, tolerate harsh industrial conditions, and exhibit desirable growth and fermentation characteristics.

My Research Contributions

Vice-Chancellor sir, large amounts of waste are generated every year from the processing of crops and animals. Agrifood waste represents the edible and inedible residual biogenic fractions of crops and animal commodities and products. It is estimated that Nigeria generates 183.3 ± 8.9MT of agrifood waste per annum (Afolabi *et al.*, 2021). These wastes are either converted to animal feed, burned or left to rot in heaps, constituting a nuisance and a source of pollution to the environment. Such common wastes in Nigeria include cassava peel (Plate 1A), rice, sorghum and wheat bran, corn cob (Plate 1B), oil palm fruit empty bunch (Plate 1C), and empty African mesquite pods (Plate 1D) among others.

Plate 1A: Cassava peel heaps

Plate 1B: Corn cob waste

Plate 1C: Oil palm empty fruit bunches

Plate 1D: Pods of *Prosopis africana*

Plates 1A-D: Examples of agricultural waste (Okike *et al.,* 2022; Dreamstime.com).

It is reported that approximately 33.33% of the food that is produced for utilisation is wasted and frittered away on a global level, which can be estimated as a loss of 1.3 billion metric tons per annum (FAO, 2021). This includes 30% cereals, 20% dairy products, 35% seafood and fish, 45% fruits and vegetables, and 20% of meat (Teneja *et al*., 2023). However, these wastes being rich in carbohydrates, proteins, fats and minerals makes them suitable substrates via microbial-biotransformation for the production of value-added products such as bioplastics, biofertilisers, food additives, antioxidants, antibiotics, organic acids, and enzymes.Nigeria is currently the largest producer of cassava in the world with an annual output of over 60million tonnes (Ikuemonisan, 2020), (Fig. 1) therefore huge amounts of cassava peels are generated as wastes which serves as one of the abundant substrates for microbial transformation.

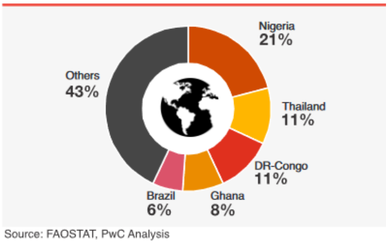


Fig. 1: Top five global cassava producers as percentage production (PwC, 2020)

Vice-Chancellor sir, in the course of my research, I have utilised cassava peel and other crop residues such as corn cobs, groundnut shell, sweet potato peel, empty bunch of palm kernel, shea nut shell, *Jatropha* seedcake, orange, banana and plantain peel, sugarcane fibre and rice bran through the activities of different microorganisms to synthesise products of industrial importance. This symbolises the activities of **microorganisms in the service of man**.

Microbial Production of Organic Acids (OA)

Microorganisms have long been utilised in various industrial processes, including the production of organic acids. These acids serve as important building blocks for a wide range of products, including food and beverages, pharmaceuticals, and biofuels. The use of microorganisms in the production of OA offers several advantages. Firstly, microorganisms can efficiently convert sugars or other carbon sources into organic acids as primary metabolites through a process called fermentation. This process often requires less energy input compared to traditional chemical synthesis methods. In addition, microorganisms can produce OA with high purity and specificity, reducing the need for extensive purification steps. This process typically occurs under controlled conditions in bioreactors or fermenters, where microbial strains are cultivated to optimize the production of specific organic acids. The industrial applications of OA cut across various industries. Acids such as lactic, citric, benzoic and sorbic acids are used as preservatives, acidity regulators, and flavour enhancers in the food and beverage industry. In agriculture, they are used as feed additives, as preservatives, growth promoters, and acidifiers to control pathogens, improve feed efficiency, enhance nutrient absorption and generally better overall animal performance. In pharmaceuticals and personal care, organic acids find application due to their antimicrobial, astringent and acidulant properties. For cleaning and sanitation, they are used in descaling agents to remove mineral deposits from surfaces, equipment and pipes in factories. In textile and leather production, OA are deployed in dyeing and finishing processes. OA are used in water treatment for corrosion control and disinfection. In green chemistry, OA serves as building blocks for the synthesis of biodegradable polymers and green chemicals. These polymers are used in packaging, textiles and automotive industries. Overall, microbial organic acids play vital roles in various industrial processes, offering sustainable and environmentally friendly alternatives to synthetic chemicals in a wide range of applications.

1. ***Itaconic Acid* (IA)**

Itaconic acid (2 methylenebutanedioic acid; $C_5H_6O_4$) is an unsaturated dicarbonic acid with high potential as a chemical building block and can be used for a plethora of industrial products including resins, plastics, elastomers, carpet and book cover coatings, adhesives, high-strength enhanced fiberglass, artificial gems, synthetic glass with nonlinear characteristics and paints.

Omojasola and Adeniran (2014) produced IA from the peel of sweet potato *Ipomoea batatas* also known as *Anomo* (Yoruba) using *Aspergillus niger* and *Aspergillus flavus.* The study reported a maximum IA production of 115.67 g $L^{-1}$by day 5 of fermentation by using 100 g of sweet potato peel. Other waste substrates used in the production of IA were palm kernel cake, producing 105.0 g L^{-1} (**Omojasola** and Adeniran, 2017); banana peel, producing 137.2 g L^{-1} (**Omojasola** and Adesina, 2017); and *Jatropha* seedcake, producing 218.0 g L^{-1} (**Omojasola** and Okwechime, 2018a).

2. ***Gibberellic Acid* (GA)**

Gibberellins are isoprenoid phytohormones which play important roles in the early germination processes of plants by activating enzyme production and mobilising storage reserves. Gibberellic acid (dihydroxy-3-methyl-6-methylene-2-oxoperhydro-4a,7-methano-9b,3-propenoazuleno[1,2-b]furan-4-carboxylic acid; $C_{19}H_{22}O_6$) is one of the most important members of the gibberellins due to its industrial and agricultural applications. GA is used in the textile industry, brewing, commercial farming and horticulture.

Kobomoje, Mohammed and **Omojasola** (2013a), **Omojasola** and Benu (2016), **Omojasola** and Adejoro (2018a and 2018b) produced GA from a variety of agro-waste substrates. These included shea nut shell (*Vitellariaparadoxa*), *Jatropha* seedcake, orange albedo (*Citrus sinensis*) and banana peel (*Musa paradisiaca*). The fermenting organisms were *Fusarium moniliforme*, *Aspergillus niger* and *Aspergillus terreus*. Our studies reported up to 32.8 g L^{-1} of GA from 3.5% concentration of substrate. In addition, these studies established that GA can be produced from these waste substrates, offering a sustainable, viable and relatively cheap alternative to synthetic GA. Infra red spectroscopy revealed that the microbially produced GA possessed three of the four bands characteristic of the synthetic GA (Fig. 2).

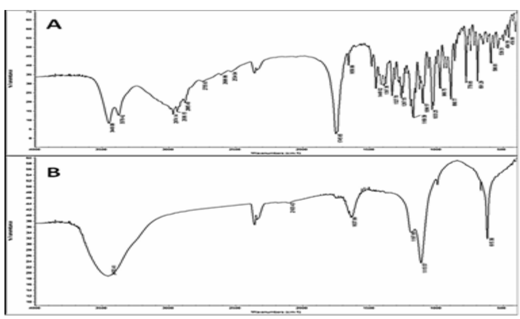


Fig. 2: FT-IR spectra of (A) standard Gibberellic acid (B) Microbially produced Gibberellic acid (**Omojasola** and Adejoro, 2018b)

3. ***Citric Acid* (CA)**

Citric acid (2-hydroxypropane-1,2,3-tricarboxylic acid; $C_6H_8O_7$) is a naturally occurring compound found in citrus fruits, with a wide range of industrial applications. It is commonly used as a flavouring, cleaning, descaling and chelating agent, pH adjuster, stabiliser and fragrance enhancer. One of the key industrial uses of CA is its role as a preservative in food and beverages. It helps to inhibit the growth of bacteria and extend the shelf life of various products. Citric acid can be synthesised chemically through oxidation using sugars and acids. While the chemical process is considered to be fast with high yields, the process is energy intensive and employs hazardous chemicals. Microbial production offers advantages in terms of sustainability, purity, cost-effectiveness with less environmental concerns.

Kobomoje, Mohammed and **Omojasola** (2013b) produced CA from shea nut shell using *Aspergillus niger*. **Omojasola***et al*. (2014) also produced CA from pineapple waste and sugarcane bagasse using *A. niger* and *Trichoderma longibrachiatum*. These studies recorded CA yields up to 2.38 g L^{-1} at 30% substrate concentration. In addition, the spent substrate was recovered after the fermentation for use as animal feed.

4. ***Oxalic Acid* (OxA)**

Oxalic acid (Ethanedioic acid; $C_2H_2O_4$)is a naturally occurring acid that can be found in many plant species, such as orange, spinach, tea, cocoa, nuts, berries and beans. It is used widely in the hydrometallurgical process and pulp industry due to its chelating properties. It has widespread industrial applications in several fields such as textiles, tanning, oil refining, catalysts, pharmaceuticals, dyes, explosives, straw bleaching, printing, marble polishing, and metal and cloth cleaning. It is also a very important chemical in petroleum, rare-earth, ink, rust, corrosion inhibitor, and dental adhesive processing.

Omojasola and Okwechime (2018b) produced OxA by submerged fermentation using *A. terreus* and *A. niger* as fermenting organisms on *Jatropha* seedcake substrate, a byproduct of biodiesel production. OxA yields were optimised to 200 g L^{-1} after 8 days of fermentation and 40% substrate concentration. This yield was also significantly higher than other recorded yields of 149.0 g L^{-1} by previous studies.

5. ***Humic Acid* (HA)**

Humic acid (disodium; bicycle [2.2.1] hept-5-ene-2,3-dicarboxylate; $C_{187}H_{186}O_{89}N_9S_1$) is a naturally occurring organic acid derived from decomposed organic matter, and it has various applications due to its unique properties. It is used in agriculture, wastewater treatment, mining and in the oil and gas industry. HA is usually produced from natural sources such as peat and compost through an alkaline extraction process. Natural HA reserves are limited and its production is considered labourious and expensive (Wang *et al.*, 2023).

Kawata, **Omojasola,** Ajiboye, Adedayo, and Bale (2023) produced HA from oil palm empty fruit bunches, a lignocellulosic-rich by product of palm oil processing in submerged fermentation. The study isolated, screened and compared the production of HA from nineteen fungi isolated from the soil of an oil processing mill. Optimal HA producers were identified as *Aspergillus niger* HRL18 and *Rhizopus stolonifer* with yields of up to 2.20 mg L^{-1} using 1% of substrate. Given its importance in agriculture, this submerged fermentation technique on the named oil palm substrate can be explored on an industrial scale to produce HA.

6. ***Lactic Acid* (LA)**

Lactic acid (2-hydroxypropanoic acid; $C_3H_6O_3$) is a very versatile acid with various industrial applications, ranging from food and pharmaceuticals to cosmetics and textiles, owing to its beneficial properties and wide availability from natural sources. In the food and beverage industry, LA is commonly used as a food additive and preservative.

Ahmed El Imam, Ighalo, Sanusi, Oke and **Omojasola** (2024) used response surface methodology to produce LA from empty pods of *Prosopis africana* (African mesquite) which is a byproduct of the production of *okpeyeh,* a local seasoning. Optimized LA yields were up to 19.72 g L^{-1} per 50 g of substrate. The fermenting organism; *Rhizopus oryzae* AK-22 was isolated from the soil. The study concluded that there is a huge potential of this abundant biomass for bioconversion into value-added products such as LA needs to be further explored.

Overall, microbial production of organic acids presents a sustainable, cost-effective, and environmentally friendly process. Indeed microorganisms ‘are working assiduously’ in the service of man.

Microbial Production of Enzymes

Enzymes are biological molecules, typically proteins, which act as catalysts in biochemical reactions. They accelerate the rate of chemical reactions by lowering the activation energy required for the reaction to occur, thereby facilitating the conversion of substrates into products. Enzymes are essential to drive a wide range of metabolic activities in living organisms and they also possess extensive applications in diverse fields, from basic research to medicine, agriculture and industrial processes

Microbial enzymes are produced by microorganisms such as bacteria, fungi, yeast, and algae. These enzymes play vital roles in the metabolism of the organism, aiding it to perform various biochemical processes necessary for its growth, survival, and reproduction. Microbial enzymes have gained significant attention and utilization in various industrial applications due to their high specificity, efficiency, and relatively low cost of production compared to enzymes sourced from plants or animals. Microorganisms are cultivated under controlled conditions to produce large quantities of specific enzymes. Fermentation processes are commonly used for enzyme production, where microorganisms are grown in bioreactors or fermenters on suitable substrates such as agricultural residues, molasses, or industrial byproducts to induce enzyme synthesis. Microbial enzymes have applications across different industries including:

i. ***Food and beverage processing***: Enzymes such as amylases are used for the production of cheese, bread, beer, wine, juices, and various other food products to enhance flavor, texture, shelf life, and nutritional value.

ii. ***Detergent manufacturing***: Proteases and lipases derived from microorganisms are used as key components in laundry detergents for effective removal of stains and greasy residues.

iii. ***Textile processing***: Enzymes like cellulases are used in textile industry for bio-finishing, desizing, stone washing, and denim bleaching processes, reducing the environmental impact compared to traditional chemical methods.

iv. ***Pharmaceutical production***: Microbial enzymes like polymerases, hydrolases and proteases are utilised in pharmaceutical manufacturing for drug synthesis, purification, and formulation, as well as in diagnostic assays and biocatalysis.

v. ***Medicine***: Enzymes have numerous applications in medical sciences. These include amylases, proteases and lipases that play crucial roles in diagnostics for kit designs, therapy in the areas of drug composition and administration, as well as research.

vi. ***Biofuel production***: Enzymes such as cellulases, pectinases and ligninases play a crucial role in biomass conversion processes for the production of biofuels such as ethanol, biodiesel, and biogas from renewable feedstocks like lignocellulosic biomass and waste materials.

vii. ***Environmental remediation***: Certain microbial enzymes such as oxidoreductases, peroxides and hydrolases are employed for bioremediation of contaminated environments by degrading pollutants such as hydrocarbons, pesticides, and heavy metals.

Microbial enzymes offer several advantages over enzymes from plant or animal sources, including rapid growth rates of microorganisms, ease of genetic manipulation for strain improvement, scalability of fermentation processes, and cost-effectiveness of enzyme production. Advances in biotechnology, such as genetic engineering and protein engineering techniques, have enabled the development of novel microbial enzymes with improved properties, stability, and specificity for specific industrial applications. Overall, microbial enzymes play indispensable roles in various industrial processes, contributing to increased efficiency, sustainability, and eco-friendliness of numerous products and processes across different sectors.

Vice-Chancellor sir, in the course of my research activities, I have produced and studied the activities of some microbial enzymes cultured on agricultural residues.

7. *Cellulases*

Cellulases are a class of enzymes that catalyze the hydrolysis of cellulose, a complex polysaccharide found in the cell walls of plants and some other organisms. Cellulose is composed of long chains of glucose molecules linked together by β-1,4-glycosidic bonds. Due to its rigid and crystalline structure, cellulose is not easily degraded by most organisms. Cellulases play a crucial role in the degradation of cellulose by breaking down the β-1,4-glycosidic bonds between glucose units, resulting in the release of glucose and other oligosaccharides. These enzymes are produced by various organisms, including bacteria, fungi, protozoans, and some animals, as well as in genetically modified organisms engineered for industrial purposes. Industrially, cellulases are utilised in the production of biofuels such as ethanol from lignocellulosic biomass. They are used in the production of textiles for biostoning and biopolishing; in laundry detergents and in the production of paper.

Omojasola *et al.* (2008) studied the activity of cellulase produced by *Trichoderma longibrachiatum, Aspergillus niger* and *Saccharomyces cerevisiae* cultured on pineapple waste. Our findings showed that maximal amounts of residual glucose liberated from the substrate was 11.74 mg mL^{-1} using 50 g of substrate by *Trichoderma.* The enzyme activity was estimated at 2.04 U mL^{-1}. When cultured on orange waste and plantain peel, the highest amounts of residual glucose produced by *Trichoderma* were 3.86 and 1.64 mg mL^{-1} using 10.0 and 5.0 g of substrate respectively. In a separate study, optimal enzyme activity was estimated to be 1.93 U mL^{-1} using orange waste and 1.83 U mL^{-1} using plantain peel (**Omojasola** and Jilani, 2008; **Omojasola** and Jilani, 2009). **Omojasola** and Jimoh (2015a, 2015b) studied the activity of cellulase on rice bran and oil palm empty fruit bunch waste substrates using submerged and solid state fermentation. Fermenting organisms, all of which were isolated from the soil of different dumpsites belonged to five genera: *Aspergillus*, *Fusarium, Penicillium, Rhizopus* and *Saccharomyces.* Highest enzyme activities were recorded with the solid state fermentations with *Penicillium citrinum* with 0.080 FPU mL^{-1} on rice bran. However, on oil palm empty fruit bunch, a combination of *Aspergillus niger* and *Rhizopus oryzae* produced enzyme activity of 0.182 FPU mL^{-1} using submerged fermentation. Oladoye, Connerton, Kayode and **Omojasola** (2014) and Oladoye, Connerton, Kayode, **Omojasola** and Kayode (2016) reported the cellulase activity ranging between 0.78–22.68 U mg^{-1} from four species of *Penicillium* on sweet potato. These experimental findings provide a window for exploration on the strength of locally available substrates that can be used to produce cellulases using indigenous organisms for industrial and other uses.

8. ***Amylase***

Amylase is an enzyme that catalyses the breakdown of starch molecules into smaller carbohydrates. It is produced naturally in various organisms, including humans, animals, plants, and microorganisms, and plays a critical role in carbohydrate metabolism. There are different types of amylases, including α-amylase, β-amylase, and γ-amylase, each with specific substrate specificities and optimal conditions for activity. Some of the key industries that use amylase include the food and beverage industry. Amylase is used for starch conversion for the production of syrups and sweeteners; in baking; brewing; and textile production.

Amao, Barooah and **Omojasola** (2019) studied amylase activities in twenty bacteria isolated from cassava peel heaps. One of the isolates *Bacillus subtilis* MH634685 recorded the highest amylase production ability with activities of 10,055 U mL^{-1} and was submitted to the gene bank. In addition to amylase, the isolates also produced cellulase and xylanase. This pluripotent property of *B. subtilis* MH634685 in enzyme production is worthy of note, particularly the huge amylase production capacity from cassava peel heaps, which is a readily available waste in our environment. Amylase production from

Penicillium brevicompactum FDC3 and *Rhodotorula anomala* with activity of 8.59 and 12.0 U mL^{-1} respectively when cultured on sweet potato was also reported by (Oladoye, Connerton, Kayode and **Omojasola** 2014; Oladoye, Connerton, Kayode, **Omojasola** and Kayode, 2016).

9. ***Collagenase***

Collagenase is an enzyme that breaks down collagen, which is the main structural protein found in connective tissues such as skin, tendons and bones. It is produced by certain bacteria, fungi and animals including humans. Collagenase plays a crucial role in various biological processes such as tissue remodeling, wound healing and the degradation of extracellular matrix components. In the food industry, collagenase is used for the tenderisation of meat, and during the fermentation of certain foods. Collagenase plays a crucial role in the leather-making process. It is also has application in biotechnology, pharmaceutical and the personal care industries.

Omojasola *et al.* (2020) studied the activity of collagenase produced by *Aspergillus flavus* JN-YG 3-5 and *Aspergillus terreus* EV8 cultured on the scales of two fish species; tilapia (*Oreochromis niloticus*) and croaker (*Pseudotolithus senegalensis*). Optimal collagenase activity yielded 0.427 U mL^{-1}; 0.323 UmL^{-1} by *A. flavus* and 0.338 U mL^{-1}; 0.290 U mL^{-1} by *A. terreus* on day 5 of fermentation in tilapia and croaker scales media respectively. This was notably higher than some previous studies and the organisms were isolated from local fish dumpsites.

The global enzymes market size was estimated at USD 12.27 billion in 2022 and was expected to reach USD 20.31 billion in 2030 (Grandview Research, 2022). However, by utilising indigenous microorganisms and agricultural waste as substrate, microbial enzyme production has the advantages of high yield, cost effectiveness, and environmental sustainability. Another example of microorganisms in the service of man.

Other Microbial Metabolites

Vice-Chancellor sir, apart from the organic acids and enzymes listed above, my team and I have also researched into some other microbial metabolic products which are of industrial importance. These products were derived through the fermentation of different agricultural wastes by indigenous microorganisms. These metabolites include bioethanol, biofertilizers, bioinsecticides, biosurfactants, exopolysaccharides, xylitol and wine.

10. ***Bioethanol***

Bioethanol is a type of renewable fuel that can be produced through the fermentation of sugars derived from biomass, such as corn, sugarcane, wheat, or other cellulosic materials. The biomass is first hydrolysed to simple sugars, which are then fermented by microorganisms, usually yeasts or bacteria, into ethanol and carbon dioxide. Yeasts, especially strains of *Saccharomyces cerevisiae*, are commonly used for this purpose due to their ability to efficiently ferment sugars to ethanol. Bioethanol is then obtained by distillation. Microbial production of biofuels has the advantages of being renewable, environmentally friendly, and can be produced using agricultural waste.

Ahmed El-Imam, Ighalo, Sanusi, Oke and **Omojasola** (2022) produced bioethanol from the empty pods of *Prosopis africana* (African mesquite) by a variety of yeasts obtained from different local sources. Our findings revealed that *Pichia kudriavzevii* SY4 produced 38.26 g L^{-1} of ethanol, therefore adding empty pods of *P. africana*; a byproduct of *okpehe* production, to the list of agricultural residues which are suitable biomass for bioethanol production. With a near zero greenhouse gases emission, the production of bioethanol from these locally available waste products is a promising stride for the country's energy sector, which has been bedeviled with numerous problems.

11. ***Biofertilizer***

Biofertilizers are substances that contain living microorganisms, typically bacteria, fungi, or algae, which colonise the rhizosphere or the interior of plants, promoting growth by increasing the supply or availability of primary nutrients to the host plant. The harmful effects of chemical fertilizers on soil, plants, and ecosystems have stimulated the growth of the global biofertilizer market. Unlike chemical fertilizers, which provide nutrients directly to plants, biofertilizers function indirectly by enhancing the nutrient uptake efficiency of plants. Biofertilizers work by fixing atmospheric nitrogen, solubilising phosphorus or other nutrients, producing phytohormones or releasing potassium from mineral or organic sources into the soil to in a form that plants can use. In comparison with chemical fertilizers, biofertilizers are sustainable, cost-effective and environmentally friendly.

Balogun, Oke, Rocha-Meneses, Fawole and **Omojasola** (2022) studied the phosphate solubilisation potential of indigenous rhizosphere fungi and their biofertilizer formulations. Three fungal inoculants; *Aspergillus niger*, *A. fumigatus* and *A. flavus* isolated from the rhizosphere of some trees were selected after screening for their phosphate-solubilisation potential. After optimisation, *A. niger*, *A. flavus* and *A. fumigatus* solubilised 549, 379 and 430 mg L^{-1} of phosphate, respectively. When used in biofertilizer formulations using sawdust and charcoal as carriers, all three inoculants maintained their fungal count above the threshold of 10^6 CFU g^{-1} after eight weeks of storage under ambient conditions. Sawdust was, however, found to be a more suitable carrier than charcoal. Being eco-friendly, these biofertilizers were recommended for use as suitable alternatives to chemical fertilizers, which carries the harmful effect of leaching into and contaminating ground or surface water. The research on biofertilizer presents opportunities and a window through which the country can attain a much friendlier and sustainable environment and boost food security through increased agricultural output.

12. ***Bioinsecticides***

Bioinsecticides are pesticides derived from natural materials, such as plants, bacteria, fungi, or minerals that are used to control insect pests. They are effective against a wide range of insect pests and are often used in integrated pest management programmes alongside other pest control methods. Microbial insecticides are derived from bacteria, fungi and viruses. They usually produce toxic substances which are active against specific groups of insects. When ingested, these toxic substances disrupt the digestive system leading to the death of the insect. Bioinsecticides offer several advantages over chemical insecticides, including reduced environmental impact, lower risk of pest resistance development, minimal negative impact on non-target organisms, and compatibility with organic farming practices. However, they may have limitations in terms of efficacy, specificity, and persistence compared to synthetic chemical alternatives.

Oduola, Adesoye, Ande, **Omojasola** and Ahmed El-Imam (2017) investigated the colony progression and impact of *Bacillus* sp. on the larval gut of *Culex quinquefasciatus*. Our findings showed 100% mortality of the 3rd larval instar of *Culex* mosquito when exposed to concentrations $\geq 1.0 \times 10^6$ CFU of the bacterial suspension. These results were achieved within one hour of exposure. These findings confirmed the efficacy of the organism and its potential to act as a biolarvicide in mosquito breeding sites that are prone to cyclical flooding. In contrast to the synthetic chemical insecticides, bioinsecticides persist for a shorter time in the environment. While this may limit their duration of action, it represents a promising outlook due to this potentially reduced environmental risk.

13. *Biosurfactants*

Biosurfactants are surface-active compounds produced by certain microorganisms such as bacteria, yeast, and fungi. These compounds have the ability to lower the surface tension between two substances, such as oil and water. Based on their chemical structure, biosurfactants are classified into different types, including glycolipids, lipopeptides, phospholipids, and polymeric biosurfactants. Surfactants reduce the surface tension of liquids, allowing them to spread more easily and interact with other substances. This property makes biosurfactants useful in emulsification, dispersion, foaming, and detergency. Biosurfactants have gained attention due to their potential applications in various industries and environmental remediation. They are useful in bioremediation of contaminated soils and water, also in oil spill clean-ups as they help in the dispersion and removal of oil from water surfaces. In agriculture, they can be used as adjuvants to enhance the efficacy of pesticides and herbicides. In food processing, they can be used as emulsifiers, stabilisers, and foaming agents. In the production of cosmetics, biosurfactants are used for their cleansing and moisturising properties in products such as shampoos, soaps, and skin care formulations. Overall, research into biosurfactants is focused on their production, characterisation, and optimisation for specific uses. Their biodegradability, low toxicity, and renewable nature make them attractive alternatives to synthetic surfactants in various applications.

Amao, **Omojasola,** Ayandele and Adewoyin (2023) isolated and characterised three bacteria; *Bacillus* sp., *Bacillus subtilis* and *Bacillus amyloliquefaciens* out of a total of eighty bacteria isolated from cassava peel heaps. These organisms demonstrated surface active properties with oil displacement values of 42.96, 41.50 and 41.54% and emulsification indices of 45.38, 4.45 and 36.0% for diesel and kerosene respectively. The study adjudged that the three isolates presented highly promising biosurfactant abilities, with *B. subtilis* possessing the highest hydrophobicity for petrol, hexadecane, diesel and toluene. This research holds some promise in the fight against environmental pollution.

14. ***Exopolysaccharides***

Exopolysaccharides (EPS) are complex polymers composed of sugars that are secreted by microorganisms, such as bacteria and yeasts. These polymers play a crucial role in the formation of biofilms, which serve as protective barriers and provide structural support for the communities of microorganisms within them and on surfaces. Certain EPS possess metal-binding properties and can be used in bioremediation processes to remove heavy metals from industrial wastewater and contaminated soil.

Using a metagenomic approach, Amao, **Omojasola** and Barooah (2019); and Amao, Barooah and **Omojasola** (2019) isolated and characterised eighty bacteria from cassava peel heaps in Ogbomoso, Nigeria and Jorhat, India. These isolates were screened for their EPS-producing potential. Our findings showed that twenty-eight isolates produced EPS with thirteen isolates classified as moderate to strong EPS producers. These isolates belonged mostly to *Bacillus, Klebsiella, Lactobacillus* and *Bifidobacterium*. These bacteria produced significantly higher ($p \leq 0.05$) quantities of EPS than the standard organism. Apart from EPS production, the isolates also produced enzymes such as amylase, cellulase and xylanase which also possess strong industrial applications.

15. ***Xylitol***

Xylitol (2R,3r,4S)-Pentane-1,2,3,4,5-pentol; $C_5H_{12}O_5$) is a sugar alcohol, also known as a polyol, often used as a sugar substitute. It occurs naturally in small amounts in various fruits and vegetables but is commercially produced from the xylan-rich hemicellulose material present in hardwoods and corncobs. Xylitol has gained popularity as a sweetener due to its similarity in taste and sweetness to sucrose (table sugar) but with about 40% fewer calories. It is used as a sugar substitute in various food and beverage products. Xylitol has a low glycemic index, which means it does not cause a rapid spike in blood sugar levels after consumption. This makes it suitable for individuals with diabetes or those looking to manage their blood sugar levels. Xylitol has also been shown to have dental health benefits. It does not promote tooth decay like sucrose and other sugars. Instead, xylitol helps to prevent cavities by reducing the growth of *Streptococcus mutans*, a bacterium primarily responsible for tooth decay. Xylitol is often found in chewing gums, candies, sugar-free drinks, syrups, lozenges, toothpastes, mouthwashes and dental floss.

Jolayemi, Oke, Rocha-Meneses and **Omojasola** (2022) cultured six fungi isolated from sawdust dump sites on undetoxified corn cob hydrolysates to produce xylitol in submerged fermentation. Our findings showed that of the six isolates, *Pachysolen tannophilus* and *Pichia kudriavzevii* produced the highest xylitol amounts of 12.82 and 12.21 g L^{-1} respectively. These amounts were increased by 31% and 18.6% respectively when the medium was supplemented with 1.5% methanol and were significantly higher ($p \leq 0.05$) than the control organism.

16. ***Wine***

Wine is conventionally produced through the alcoholic fermentation of the juice of ripe grapes *Vitis vinifera* or any fruit with a good proportion of sugars such as citrus fruits, bananas, apples, mangoes and so on. Other non-conventional substrates including cereals and flowers can also be used in wine production as long as they have sufficient sugars to produce ethanol which is the principal product of the fermentation. **Omojasola** and Ademuyiwa (2003) produced "Roselle wine" from the fermentation of the extract of *Hibiscus sabdariffa* (popularly called *zobo*) using *Saccharomyces cerevisiae.* The extract was supplemented with 12% sucrose as it contained no natural sugars. The aerobic phase of the fermentation was for five days, while the anaerobic phase lasted 21 days. The end product was a red, still, sweet wine with a residual sugar content of 0.75 mg mL^{-1} and a final alcohol content of 7% v/v.

At this juncture, it can be observed that microorganisms are not only serving man by producing metabolites relevant to key industries in food, pharmaceuticals and agriculture, but microorganisms are also crucial in the production of alcohol, an important ingredient in celebrations and merry making. Therefore, microorganisms are also serving man in the business of jollification and merry making!

Other Research Contributions

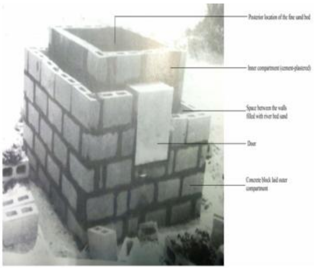
Vice Chancellor sir, my research efforts have not confined to the production of the industrial microbial metabolites from agricultural residues enumerated above, I have also researched into the preservation of foods and indigenous beverages, the microbiological quality assessments of foods and the phytochemical constituents and antimicrobial activity of some indigenous plants.

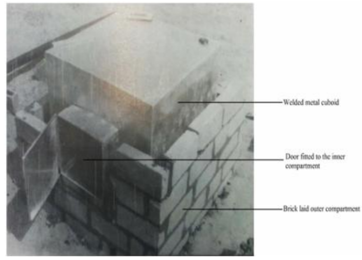
I. Food Preservation

For Nigeria to attain the Sustainable Development Goal 2, adequate attention must be paid to reducing postharvest food loss among other strategies. The Federal Government speaking through the then Minister of State for Agriculture and Rural

Development at the International Organization for Standardization (ISO) certification of the Nigerian Stored Product Institute (NSPRI) in Abuja in 2022 estimated Nigeria's post-harvest losses at ₦3.5 trillion annually (Ewepu, 2022). Stemming these losses will help to strengthen our food security. **Omojasola** and Fawole (2012) in reviewing traditional methods of food preservation such as sun-drying, salting, smoking and fermentation concluded that traditional food preservation methods are usually simple to use, efficient, cost-effective and eco-friendly. They are very useful, deployable and dependable especially in rural areas.

Preservation of Leafy Vegetables: Omojasola *et al.* (2022a) evaluated the use of block-in-block (BB) and metal-in-block (MB) evaporative coolant systems (ECS) on the shelf life and nutritional quality of *Amaranthus hybridus* (green amaranth; Yoruba *efo tete*) and *Telfairia occidentalis* (fluted pumpkin; Igbo *ugu*). The ECS is a product developed by the Nigerian Stored Product Research Institute (NSPRI), a governmental body charged with the mandate of developing technologies for postharvest management and improvement in the quality of Nigerian agricultural commodities (Plate 2). Our findings revealed that MB and BB ECS extended the shelf life of the vegetables for seven days which was longer than the three days at ambient storage. Although a general decline in some nutritional parameters was observed, MB-preserved samples showed better retention of vitamin C and carbohydrate. The loss of minerals was observed in the ECS-preserved samples. MB-preserved samples recorded reduced susceptibility to microbial colonization and spoilage. The study concluded that ECS structures can be easily adopted by rural farmers for the reduction of postharvest losses of vegetables.





A. Block-in-Block ECS B. Metal-in-Block ECS

Plate 2: NSPRI's Evaporative Cooling Structure (NSPRI, 1990).

Preservation of Tomato: Despite the large volumes produced annually, postharvest decay is a significant challenge in the tomato industry which is informed by poor storage technologies. **Omojasola** *et al.* (2022b) investigated the preservative effect of local wood ash (LWA) and the ash of *Azadirachta indica* (AWA) on the physicochemical and microbiological quality of tomato (*Solanum lycopersicum*) fruits. The results of our study showed that the use of wood ash is an effective alternative for extending the shelf life and preventing spoilage of tomatoes. Both LWA and AWA extended the shelf life of the tomato fruits for up to 4 weeks (Plate 3) while the control fruit got completely decayed in three days under similar ambient conditions. Ash treatment used in this study also preserved the antioxidant components of tomatoes such as lycopene, phenolics, and ascorbic acid contents. Therefore, the use of wood ash in preserving tomatoes is a promising option for preventing recurring postharvest losses from microbial spoilage and loss of product quality. Poor storage or improper handling is a major cause of post-harvest losses incurred by farmers. The use of these local materials, as demonstrated in this research, with proven results, can be developed further to help farmers mitigate post-harvest losses and also ensure perennial availability of these perishable crops. This research, therefore, presents a potential opportunity for investors for a scale up.

Plate 3: Tomato fruits preserved in wood ash for 4 weeks (**Omojasola** *et al.*, 2022).

Preservation of Fish: Idris, Omojowo, **Omojasola**, Adetunji and Ngwu (2010) treated fresh catfish (*Clarias gariepinus*) with different concentrations of 2.5-10% ginger. Our findings showed that the dipping of fish in different concentrations of ginger before smoking had beneficial effects on the overall quality of the final products. The free fatty acid and trimethylamine contents as well as the fungal counts were significantly reduced in the treated fish. In another study, Omojowo, **Omojasola,** Kolawole, Ngwu, Oluborode and Adetunji (2010) treated fresh catfish with 20-25% brine before smoking. Our findings showed that the treated samples were negative for *Escherichia coli* and *Streptococcus* sp. The treatment effectively reduced the total viable counts, coliform, staphylococccal and fungal counts after smoking and these low microbial counts were maintained until the end of the 8 weeks of storage. Omojowo, **Omojasola** and Ihuahi (2008) and Omojowo, **Omojasola,** Idris and Ihuahi (2009) treated samples of fresh catfish with different concentrations of citric acid and potassium sorbate before smoking. Our findings showed that all treated samples were negative for the presence of *E. coli* and *Streptococcus* sp. In addition, these had higher protein and amino acid contents than the control at the end of 8th week of storage.

Preservation of *Kunun zaki*: *Kunun zaki* is a popular and widely consumed non-alcoholic, fermented millet-based beverage in Northern Nigeria. The cereals used in its production are millet, sorghum and maize and is normally flavored with ginger, with or without the addition of sugar as sweetener. Without preservation, the *Kunun zaki* begins to deteriorate within hours of production (Elmahood and Doughari, 2007).

Omojasola and Davies (2015) investigated the effect of pasteurization, refrigeration and some chemical preservatives; sodium benzoate and sodium metabisulphite, on the shelf life of *Kunun zaki*. Our findings revealed that a combination of pasteurization, chemical treatment and refrigeration can extend the shelf life of *Kunun zaki* to 27 days, therefore giving ample time for product retailing.

Preservation of *Agadagidi:* *Agadagidi* is an alcoholic beverage made from overripe plantain pulp. It is consumed among the Yoruba speaking areas of South-west Nigeria. The fermentation of overripe plantain to produce *Agadagidi* is a waste prevention processing of plantain, a perishable crop which has much less value when it is overripe. *Agadagidi* like many other indigenous fermented foods and beverages is faced with the challenge of a short shelf life and microbial-induced spoilage within a few days of production. **Omojasola** *et al.* (2012) evaluated the effect of chemical preservatives, pasteurization and refrigeration on the shelf life of *Agadagidi*. Our findings showed that the rapid deterioration of *Agadagidi* can be prevented and the shelf life extended from the traditional 2-3 days to 8 weeks and still find consumer acceptability with the use of 0.1% sodium benzoate and refrigeration at 5°C which was recommended by the study. The tripartite treatment of these indigenous drinks, therefore, showed that large scale production of *Kunun zaki* and *Agadagidi* is feasible for greater economic benefits to the country.

II. Microbiological Quality Assessments of Foods

Vice-Chancellor sir, the microbiological quality assessment of local foods is essential for ensuring food safety and preventing the transmission of foodborne illnesses. By conducting microbiological quality assessments of local foods and implementing appropriate control measures, stakeholders can ensure the safety and quality of these foods, protect public health, and promote consumer confidence in traditional and culturally significant food products. Government regulatory agencies such as the National Agency for Food and Drug Administration and Control (NAFDAC) play a crucial role in food regulation to protect public health, ensure food safety, and maintain consumer confidence. Their responsibilities encompass various aspects of the food industry, including production, processing, distribution, labelling, and marketing.

Fish: Omojowo and **Omojasola** (2012) evaluated the microbiological quality of 2,800 tilapia (*Oreochromis niloticus*) and 2,800 catfish (*Clarias gariepinus*) (Omojowo and **Omojasola**, 2013a) raised in ponds fertilized with treated and untreated cow and poultry manure. Our findings showed that pathogenic enteric bacteria such as *Escherichia coli, E. coli* O157.H7, *Salmonella typhi, Shigella dysenteriae* and *Aeromonas hydrophila* were recovered from the skin, gills, internal organs and muscle of the fish from ponds fertilized with untreated cow and poultry manure while they were absent in the muscle of fish from ponds fertilized with treated manure. These pathogens showed multiple resistance patterns to some antibiotics tested (Omojowo and **Omojasola**, 2013b, 2013c). The presence of these pathogens portends a threat to the fish, handlers, consumers and the environment. Owolabi, **Omojasola,** Abioye and Aina (2019) investigated the physiological and bacteriological profiles of catfish (*Clarias gariepinus*) exposed to municipal waste leachate. Our findings revealed the presence of bacteria in all organs of the fish including the muscle. The total bacterial counts exceeded levels accepted by the International Commission on the Microbiology Specification of Foods. In addition, the fish was exposed to heavy metals such as cadmium, copper, iron, lead, manganese and zinc which produced histopathological changes in the fish. Anibijuwon, **Omojasola,** Odaibo and Adelabu (2017) examined the microbial content of frozen fishes retailed in Ilorin markets. The findings revealed the presence of some pathogenic and toxigenic microorganisms such as *E. coli, Pseudomonas aeruginosa, Proteus, Staphylococcus, Micrococcus, Salmonella typhi, Shigella dysenteriae, Klebsiella pneumoniae, Bacillus subtilis, A. niger* and *A. flavus* in the fish samples. In addition, bacterial and coliform counts exceeded levels specified by governmental food regulations.

Dried Yam Chips: White yam (*Dioscorea rotundata* Poir) is a staple food in West Africa and is a good source of carbohydrates and nutrient energy. West Africa is the most important yam-producing region in the world with Nigeria ranking as the leading global producer of white yams, accounting for 66% (approximately 50.1 million tons) of annual global production (FAO, 2021). Lack of adequate storage facilities leads to rapid physiological and microbiological deterioration of the yam tuber and to prevent heavy losses fresh yam tubers are processed to dried yam chips. While dried yam chips are more storage stable than the yam tubers, a major problem faced by the storage of the dried yam chips is deterioration mainly due to fungal contamination which has food safety considerations if the moulds are toxigenic. **Omojasola** and Sanu (2013) evaluated the microbiological quality of dried yam chips (*egbodo*) stored for six months. Our findings revealed the presence of eleven fungi, of which some were toxigenic and five bacteria. Analysis of the samples for the presence of Aflatoxin B_1 showed <2ppb in all the samples over the storage period. This presence of Aflatoxin B_1 raises serious public health concerns as it is a potent heptocarcinogen and a major risk factor for hepatocellular carcinoma, a very aggressive human cancer with a very poor prognosis. In addition, insect infestation of the samples occurred during the storage period. Four species were identified; these were *Tribolium casteneum, Dinoderus porcellus, Rhyzopertha dominica* and *Sitophilus zeamais*. The study recommended that the traditional practice of open air sun-drying of yam chips should be discouraged; rather oven drying to minimize microbial contamination was advocated. In addition, sorting to exclude extraneous material and minimize mouldiness and insect infestation was suggested.

Poultry Feeds: Poultry feeds are specially formulated to provide the essential nutrients required for the growth, health, and productivity of poultry birds, including chickens, turkeys, ducks, and quail. However, animal feeds are usually not subjected to the same stringent microbiological criteria and standards as the food consumed by humans. The use of poor quality ingredients has led to the production of poor quality feeds. The microbiological quality of poultry feeds is a critical aspect of feed safety and poultry health. Contamination of feeds with harmful microorganisms can lead to poultry diseases, reduced productivity, and food safety risks for consumers. **Omojasola** and Kayode (2015) investigated the microbiological quality and physico-chemical properties of selected poultry feeds from commercial feed millers in Ilorin. Our findings revealed the presence of twelve microorganisms comprising seven bacteria and five fungi including some with medical and public health significance such as *Staphylococcus aureus, Bacillus subtilis, Bacillus cereus, Klebsiella sp., Proteus sp., Pseudomonas aeruginosa, Escherichia coli* and *Aspergillus niger, Aspergillus flavus, Coccidiolodes immitis*. The findings showed that while most of the microorganisms isolated from the feed samples used in this study were common environmental contaminants, the overall microbiological quality of the feeds fell below international microbiological standards. The study recommended aseptic handling and processing of commercial and home mixed poultry feeds. Proper sanitation procedures should be carried out in storage facilities to ensure that all poultry feeds produced are of good microbiological quality.

III. Phytochemical Screening and Antimicrobial Activity of Some Indigenous Plants

Africa is renowned for its rich biodiversity, has a vast array of plant species that are used traditionally for medicinal purposes. These plants often contain bioactive compounds with potential antimicrobial properties. Several indigenous communities have long relied on traditional herbal remedies derived from local plants, to treat various infectious diseases and other ailments. Thus African indigenous plants represent a valuable source of natural products for drug discovery and development. Many modern pharmaceuticals, including antibiotics and antifungal agents, have been synthesised from plant-derived compounds. As antibiotic resistance continues to rise globally, there is increasing interest in exploring the antimicrobial properties of these plants as potential sources of alternative or adjunct therapies. Screening these plants for antimicrobial activity can validate their traditional uses, identify novel sources of antimicrobial agents, and may lead to the discovery of new drugs or therapeutic agents to combat drug-resistant pathogens. Awe and **Omojasola** (2003), **Omojasola** and Awe (2004) and Awe and **Omojasola** (2009) investigated the antibacterial activities and phytochemical constituents of the following tropical plants: *Anogeissus leiocarpa* (African birch; English) local names: *Marke* Hausa; *Kojoli* Fulani; *Atara* Igbo; *Ayin* Yoruba - Plate 4A; *Anacardium occidentale* Cashew - Plate 4B; *Gossypium hirsutum* L., Upland cotton- Plate 4C; and *Piliostigma reticulatum* (DL) Hochst, common name: Purple orchid tree; Yoruba *Abafin*; Hausa *Kalgo*; Igbo *Okpo atu* - Plate 4D. Decoctions of parts of these plants are used traditionally in the treatment of a variety of oral and gastrointestinal infections. Clinical isolates of *Escherichia coli*, *Shigella dysenteriae*, *Salmonella typhimurium, Staphylococcus aureus* and *Pseudomonas aeruginosa* were challenged with different concentrations of aqueous and ethanolic extracts of the leaf and stem bark of the test plants. They were also screened for their phytochemical contents.

4A. *Anogeissus leiocarpa*

4B. *Anacardium occidentale*

4C. *Gossypium hirsutum*

Plate 4A-C: Some indigenous plants screened for antibacterial and phytochemical properties (Brunken *et al.*, 2010).

The findings revealed a dose-dependent activity against all the test organisms, with minimum inhibitory concentrations (MIC) ranging between 0.025-0.25 % w/v. The plants were also found to contain bioactive components such as alkaloids, cardiac glycosides, saponins, tannins phenolics, steroids and phlobatinins in varying amounts. The studies concluded that these plants were promising candidates for anti-diarrhoeal drugs and further studies needed to be carried out to isolate the bioactive compounds in the plant extracts.


4D. *Piliostigma reticulatum*


4E. *Daucus carota*


4F. *Myristica fragrans*

Plate 4D-F: Some indigenous plants screened for antibacterial and phytochemical properties (Brunken *et al.*, 2010).

Anibijuwon, **Omojasola,** Olayiwole, Abioye and Odaibo (2013); Anibijuwon, **Omojasola,** Abioye and Gbala (2017) and Okutue and **Omojasola** (2018) studied the antibacterial activities and phytochemical properties of *Daucus carota* (wild carrot) (Plate 4E), *Myristica fragrans* (nutmeg) (Plate 4F), and *Terminalia glaucescens* (smooth-fruited Terminalia). Decoctions of these plants are used in traditional medicine in the treatment of various oral and intestinal disorders. Extracts of these plants were screened for their phytochemical content and also used to challenge selected enteric and food poisoning bacteria. Our findings revealed that different concentrations of the ethanolic and methanolic extracts of *M. fragrans* showed appreciable bactericidal activity against the test organisms with MIC of 0.20-0.50% w/v. *D. carota* showed antibacterial activity against *Staphylococcus aureus, Streptomyces scabies, Bacillus subtilis, Bacillus cereus, Pseudomonas aeruginosa* and *Escherichia coli.* The root extracts contained phenolics, carotenoids, polyacetylenes, and ascorbic acid. *T. glaucescens* showed appreciable bactericidal activity against *E. coli* with MICs ranging from 0.025-0.10% w/v. Root extracts contained anthraquinones, alkaloids, triterpenes, flavonoids, saponins, tannins and phenols. The most abundant bioactive components of *T. glaucescens* were identified as catechol, ethyl iso-allocholate and 2-nonadecanone-2,4-dinitrophenylhydrazine.

Other Antimicrobial Agents

Obaleye, Tella, Osunniran, Simon and **Omojasola** (2014) synthesised, characterised and evaluated the antimicrobial activity of a novel --M-X-M-X--- type Infinite Chain 1D Cu(II) Complex with Eflornithine Hydrochloride Hydrate as Ligand. A ligand is an ion or molecule which donates a pair of electrons to the central metal atom or ion to form a coordination complex. The Eflornithine Hydrochloride Hydrate ligand (EFL) has been reported to be effective in the treatment of human African trypanosomiasis. The copper II complex C(II)C and EFL were challenged with clinical isolates of *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa.* Findings showed that the metal-drug complex possessed a measure of antibacterial activity against all the test organisms. The activity of the ligand EFL was bacteriostatic against all the organisms tested, while that of the C(II)C was bacteriostatic against *E. coli* and *P. aeruginosa* but bactericidal against *S. aureus* at 0.0001g L^{-1} concentration. The data showed that the complex exhibited more efficient antibacterial activity than the free ligand. These findings revealed the potential of this metal complex ligand in the development of novel metal-based drugs.

Conclusion

Vice-Chancellor sir, the beneficial role of microorganisms in transforming agricultural wastes into raw materials of industrial importance is a promising avenue for sustainable resource utilization and waste management. Through various metabolic processes, microorganisms can efficiently break down complex organic compounds present in agricultural wastes into simpler, valuable products that can be utilised in industrial applications. This process not only helps to alleviate the burden of agricultural waste pollution and disposal but also contributes to the development of bio-based industries and the reduction of dependency on fossil fuels. Microbial-mediated transformations of agricultural wastes offer several advantages, including:

Resource Recovery: By converting agricultural wastes into valuable raw materials, microorganisms facilitate the recovery of resources that would otherwise go to waste. This enhances resource efficiency and reduces the environmental impact associated with waste accumulation and disposal.

Value-added Products: Microorganisms can produce a wide range of value-added products from agricultural waste, including enzymes, organic acids, biopolymers, and bioactive compounds. These products have diverse industrial applications in sectors such as food and beverages, pharmaceuticals, cosmetics, and bioplastics manufacturing.

Circular Economy: Integrating microbial biotechnology into agricultural waste management promotes the principles of the circular economy by closing the loop between waste generation and resource utilisation. By converting waste streams into valuable inputs for industrial processes, microbial-based technologies contribute to the creation of sustainable, closed-loop systems.

Research into food preservation highlights the critical importance of safeguarding food quality, safety, and availability throughout the food supply chain. Improved food preservation techniques offer reduced food wastage and increases availability of foods with preserved sensory and nutritional qualities. The exploration of antimicrobial properties within African indigenous plants represents an intersection between traditional wisdom and modern scientific inquiry. This offers significant promise for addressing national health challenges. These natural compounds offer a rich source of new antimicrobial agents that could potentially mitigate the growing threat of antimicrobial resistance, which poses a serious public health concern worldwide. This is important in regions where access to conventional antibiotics and healthcare resources may be limited. In summary, harnessing the beneficial role of microorganisms through continued research, innovation, and collaboration is essential for unlocking the full potential of microbial biotechnology in addressing global challenges related to waste management, conservation and resource scarcity.

Recommendations

Vice-Chancellor sir, I want to make the following recommendations which I am certain, will amplify the essence of microorganisms in the service of man.

1. Industrial production of indigenous microbial products: Despite the considerable quantum of knowledge available from research, the production of indigenous microbial products remains localised and small-scale, with their production methods fossilised in the traditional way. Nigerian industries and microbiology graduates should venture into commercial scale production of products like *Ogi*, *Iru*, *Okpehe*, *Nono*, *Kunun* and *Agadagidi* with enhanced shelf life and modern, appealing packaging.
2. Microbial metabolites produced by each waste can be done at the site of each waste employing simple to operate bioreactors. The products can then be pooled to supply big industries.
3. The successful implementation of microbial-mediated transformations of agricultural wastes into industrial raw materials requires addressing various challenges chief of which is increased funding. Meaningful research takes time and costs money. Nigerian researchers need to be supported with up-to-date research technology and constant power supply. An increase in budgetary allocation for Education, Science and Technology is required for Nigeria to reach her full potential for research and development.
4. Proper and effective implementation of food preservation strategies requires interdisciplinary collaboration among stakeholders across the food industry, academia, and government.
5. Special collaborative relationships should exist between the University, Research Institutes and the Industry. This will play a crucial role in driving innovation, advancing

knowledge, and fostering economic development. These collaborative partnerships will bring together diverse expertise, resources, and perspectives that will address our challenges, accelerate scientific discoveries, and translate research findings into real-world applications.

6. The unlocking of the full potential of African indigenous plants as sources of antimicrobial agents requires concerted efforts and collaboration across multiple disciplines. It is essential to encourage such partnerships to fully develop novel drugs that will be effective in combating antibiotic resistance.

7. It is imperative to prioritise ethical considerations, including the protection of traditional knowledge, intellectual property rights, and equitable benefit-sharing with local communities. Respectful engagement with indigenous knowledge holders and collaboration with local stakeholders are essential for ensuring culturally sensitive and sustainable research practices.

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