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LADOKE AKINTOLA
UNIVERSITY OF TECHNOLOGY
OGBOMOSO, NIGERIA

THE NEXT BIG THING IS VERY SMALL:

THE PARADOX OF DIMINUTIVE MICROBES AND NANOPARTICLES

AGBÁJÉ LATEEF
B. Tech., M. Tech., Ph.D (LAUTECH), Cert. Mol. Biol. (Mysore)
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By

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CITATION OF PROFESSOR A. LATEEF

Prof. Agbaje LATEEF was born in Apòmù, Ìsokan LGA, Osun State on 24 February, 1972 to Alhaji and Alhaja Abd Lateef Ajagun Garuba of Àgberí compound, Apòmù. He attended Ansar-Ud-Deen Primary School, Adífá, Apòmù (1978-1983) and African Church Grammar School, Adífá, Apòmù (1983-1988). He was the best student at various times, which culminated into his appointment as the Senior Prefect Boy during 1987/1988 academic session. Prof. Lateef passed his WASC examinations in flying colours with Division I, and later got admitted to the then Oyo State University of Technology, Ogbomoso in 1990 (now Ladoke Akintola University of Technology, Ogbomoso) as one of the pioneer students to read Pure and Applied Biology.

Prof. Lateef obtained Bachelor of Technology, Second Class (Upper Division) in Pure and Applied Biology in 1997. Prof. Lateef served the nation under NYSC scheme at Jigawa State during 1997/1998, after which he joined the services of his *alma mater*, LAUTECH as a Graduate Assistant in the Department of Pure and Applied Biology in September, 1998. He later obtained Master of Technology in Biotechnology (Distinction) and Doctor of Philosophy in Microbiology in 2001 and 2005 respectively from Ladoke Akintola University, Ogbomoso, Nigeria. He received advanced training in fermentation technology, enzyme technology, biocatalysis, functional foods and molecular biology at the prestigious CSIR-Central Food Technological Research Institute, Mysore, India. He has twenty-two years of research, teaching and administrative experiences in the University with vast interests in

Industrial Microbiology and Biotechnology, especially fermentation processes, enzyme technology and nanobiotechnology. He rose through the ranks, from a Graduate Assistant in 1998 to a Professor of Microbiology in 2013.

An astute researcher, Prof. Lateef has won awards and grants within the University, and at national and international levels in his field. He channeled the grants to establish a well-equipped Laboratory of Industrial Microbiology and Nanobiotechnology in 2014. In 2013, he was adjudged the maiden winner of Prof. Oyewale Tomori National Prize for Young Scientists in Microbiology, which was awarded by The Nigerian Young Academy (*NYA*), an affiliate of The Nigerian Academy of Sciences (*NAS*). He has served the Department of Pure and Applied Biology, Faculty of Pure and Applied Sciences and the University in several capacities. He was examination officer of Department from 2010-2012. He was on secondment to the Department of Science Laboratory Technology as Acting Head of Department during 2012-2014, during which the B. Tech Science Laboratory Technology programme was first fully accredited by National Universities Commission (NUC) and Nigerian Institute of Science Laboratory Technology (NISLT). At the faculty, he was chairman of exhibition committee (2007-2012), member, committee on development of website (2009), member of review panel (2008-Till Date), and Chairman, committee on the creation of new programmes (2019-2020) among others.

He was a member of LAUTECH Consultancy Services (2008-2012), University Admissions Committee (2011-2012), the University Implementation Committee on Open and Distance Learning (2012-2015); and Management Committee of Central University Research laboratory

(2014-2016). He was the first alumnus to be appointed as the Head of Department of Pure and Applied Biology, LAUTECH, the position which he held from 2015-2018, during which full NUC re-accreditation status was obtained for the B. Tech programme of the Department. At the moment, he is the Director/Chief Scientist, Central Research Laboratory, and Senate representative on Governing Council of LAUTECH, Ogbomoso. He has served as external examiner to several Universities in Nigeria, South Africa and India, as well as member of NUC accreditation teams to some Nigerian Universities. He has also assessed many candidates for Professorial positions in Universities in Nigeria and South Africa. He has been a consultant to Fondazione Cariplo, Italy since 2016 on evaluation of proposals for funding of researches in Bioeconomy, and also a reviewer for National Research Foundation of South Africa on the rating of scholars. Professor Lateef has reviewed for more than eighty journals in all the continents of the world.

He has supervised more than two hundred undergraduate students, and twelve postgraduate candidates. He is the Head of Nanotechnology Research Group ($NANO^{+}$) in LAUTECH, Ogbomoso, Nigeria (www.lautechnanotech.com), a group founded in September 2014 which has promoted nanotechnology research in the country. He has led the research group to organize workshops and conferences on nanotechnology in 2017, 2018, 2019 and 2020. The group has been described as a focused research group with unparalleled leadership in biomimetic nanotechnology in Nigeria. Activities of the group also led to the publication of an issue of *Science Focus* Vol. 23 (2) 2018 and Vol. 805 of *IOP Conference Series: Materials Science and Engineering* (Institute of

Physics, UK) dedicated to the publishing of papers presented at the LAUTECH NANO 2018 and 2019 conference respectively. He is the Editor-in-Chief of *Nano Plus: Science and Technology of Nanomaterials.*

Though, a full-blooded Ladokite having obtained all his degrees in this University, Prof. Lateef is a scholar of international repute; his works are major contributions in Microbiology, Biotechnology and Nanobiotechnology and widely sought after. He has one hundred and twenty-three publications in reputable journals and books to his credits, sixty-one of which are in nanobiotechnology, and seventy-five published after his last promotion in 2013. His articles have enjoyed good citations among his peers worldwide. He ranks as the 4th most cited author on Google Scholar in LAUTECH, and has the highest *h*-index of 34 among LAUTECH scholars. In Scopus, he has the highest *h*-index of 25 and also ranks 1st among LAUTECH scholars by publishing 79 articles in Scopus-indexed journals/books. He ranked 104th among top 500 scholars in Nigeria (2014-2020) by SciVal of Elsevier BV, Netherlands. Prof. Lateef is a firm believer in the principles of Academic Staff Union of Universities (ASUU), and he has been a member of expanded executives in LAUTECH for more than a decade.

In Apomu, his hometown, Prof. Lateef is the Chairman, Board of Governors and President of the Old Students' Association of African Church Grammar School (AFROGOSA), and the Chairman, Education Development Committee of Apomu Descendants' Union (ADU). He is also a member of Afrique Club, Apomu and Apomu Council of Youths (ACOY).

Prof. Lateef is married to Anifat Omowumi and blessed with three lovely children: AbdusSalaam Taiwo, AbdusSataar Kehinde and Islamiyah Idowu.

Protocol

The Vice-Chancellor,
The Deputy Vice-Chancellor,
The Registrar,
The Bursar,
The University Librarian,
Provost, College of Health Sciences,
Dean of Postgraduate School,
Dean of the Faculty of Pure and Applied Sciences,
Deans of other Faculties,
Acting Dean of Students' Affairs,
Members of the University Senate,
Members of the University Community,
Your Royal Highnesses,
My Lord Spiritual and Temporal,
Distinguished Guests, Friends and Families,
Gentlemen of the Press,
Greatest Nigerian Students,
Ladies and Gentlemen.

1.0 Preamble

It is a great privilege to stand at this gathering this day and also a special grace by the almighty *Allah,* the giver of life, the owner of knowledge, and the all-knowing to deliver an inaugural lecture that chronicles my research activities in microbiology, biotechnology and nanobiotechnology in the last twenty-two years in my *alma mater,* the greatest Ladoke Akintola University of Technology, Ogbomoso, Nigeria. This is an inaugural lecture by a full-blooded Ladokite; someone who has been on ground since the inception of the University as a pioneer student in 1990. In this connection, I wish to thank my teacher and the Vice-Chancellor, Prof. Michael Olufisayo

Ologunde for allowing his student to make this presentation.

This is the 12th inaugural lecture from the Faculty of Pure and Applied Sciences, the 3rd from the Department of Pure and Applied Biology, the 3rd by former undergraduates of LAUTECH anywhere in the World (after Prof. O.J. Alamu of Osun State University, Osogbo and Prof. E.B. Gueguim-Kana of the University of KwaZulu-Natal, South Africa), but the 1st to be delivered by a former undergraduate student of LAUTECH in this University, and also 1st in nanobiotechnology in Nigeria. The essence of inaugural lecture is for a Professor to communicate his/her research activities with a larger audience of town and gown. Though, I was appointed as a Professor on October 1, 2013 through an announcement that came on April 7, 2015; today is the appointed time for me to deliver the inaugural lecture to exterminate the debt that I owe the academic community and public at large.

2.0 My Voyage as a Biologist, Microbiologist, Biotechnologist and Nanobiotechnologist

Mr. Vice-Chancellor, Sir, I did not set out to read life sciences, let alone specializing in biology judging from my secondary school days. As a small boy at African Church Grammar School, Apomu, I developed interests in physical sciences; particularly mathematics, chemistry, physics and additional mathematics at senior class. The personality of one of my mentors, brothers and lesson teachers, Prof. Memudu O. Olatinwo (Department of Mathematics, Obafemi Awolowo University, Ile-Ife) influenced me so much that I opted to study mathematics by filling the course in my JAMB form in 1989. When my father got to know about this, he said '*Ìsirò báwo lo fé se* (why would

you decide to study mathematics?). So, I was pressured to change it to Pharmacy, but I could not make the cut-off point. My lukewarm interest in biology was obvious to the extent that my biology teacher, Mrs. Roselyn Ekanem-Apooyin often looked at me scornfully for lack of interest in biology. Even the dexterity of my Principal, Mr. Ishola Moshood Kalenikanse (a Zoologist) at teaching biology could not sway my interest in the subject. For this, I paid a prize, because when our results came out, I had a P7 in biology! I must thank God for the efforts of my former English language teacher, Late Chief Asimiyu Bababunmi, who had earlier influenced my father to register me for GCE in 1989. So, I carry the burden of using two O' level certificates up till today because of biology.

To prepare me for the almighty UME again, I was registered at the popular Universal Tutorial College, Ile-Ife [owned by Dr. (Chief) Rahmon A. Adedoyin, the proprietor of Oduduwa University, Ipetumodu]. At the end of the programme, I sat for UME, but was unable to meet the cut-off point for Pharmacy at Obafemi Awolowo University, Ile-Ife. Thus, I prepared to become an animal scientist by procuring form to the Federal College of Animal Health and Production Technology, Moor plantation, Ibadan, of which I was offered admission for OND programme in animal husbandry. I was already registering for the programme when the admission letter to study Pure and Applied Biology at the just established Oyo State University of Technology (OSUTECH), Ogbomoso came from nowhere!

I sought the opinions of some of my seniors who were in higher institutions, with the advice that I should take-up the admission. That was how I began my journey to Ogbomoso with the transport fare of six naira and fifty

kobo. I had passed through Ogbomoso before in 1987, while going to Ilorin for holiday visit to my late maternal uncle (Chief Ganiyu Ogunmodede). Then, I saw *Aláta* this, *Aláta* that in terms of enterprise and industries. So, while I was reporting to the University in October, 1990, my father (*Abiyamo tòtóó*) followed me with some of my loads on his head to Ogbomoso. He went back home the same day after settling me down at the now rested *Stadium Hostel.* So, my studying biology was accidental, never planned, but '*Alhamdulillah'* as the rejected stone now puts food on my table, and is the giant on whose shoulder I now stand. I made up my mind to excel in the study, which came to fruition as I graduated with Second Class (Upper Division) in Pure and Applied Biology coming second after my friend of thirty years, Prof. Musibau A. Azeez.

The journey to becoming a biotechnologist started with the scintillating lectures of my emeritus supervisor, Prof. Julius Kola Oloke who introduced so many fantastic things about applications of microbes to us starting from 1993. In fact, it was from Prof. Oloke that I first heard of 'e-mail' in 1995, when he would tell us that he was going to OAU, Ile-Ife to check his e-mail. He is such a forward-looking and progressive scholar. I also had opportunity to offer a biotechnology course in the Department of Chemical Engineering, which was taught by both Late Prof. J.O. Edewor and Prof. B.O. Solomon (Former DG/CEO of National Biotechnology Development Agency, Abuja).

So, when it was time for us to proceed on industrial attachment, I had interest to lay my hands on biotechnology. Therefore, I sought placement with a federal agency at Ibadan, but after about a month, it became clear to me that I won't gain anything, so I decided to come back to Ogbomoso. I met Prof. Oloke and he offered to

supervise me under SIWES. That was where and how I cut my teeth in terms of research. I carried out extensive work on propagation of *Rhizobium meliloti* and applied the inoculants (using cow dung as carrier) on cowpea on experimental farm. During the course of the project, he proceeded to Canada on Postdoctoral fellowship, while Prof. Moses A. Osundina (Rtd) continued with the supervision of the project. It was an eye-opener for me to see wonders of microbes, even as I realized that the project was an offshoot of the M.Sc thesis of Prof. Oloke at OAU, Ile-Ife. This was followed with my undergraduate project on the antibacterial and mosquitocidal activities of seed and pulp extracts of *Aframomum melegueta* (Alligator pepper).

After graduation in 1997, I was posted to serve the nation in a secondary school at Jahun, Jigawa State. During one of my trips home, I branched at LAUTECH and after interaction with Prof. Oloke, I was encouraged to submit my CV/application letter as the University was contemplating to employ graduate assistants. After a rigorous interview chaired by Prof. O.O.P. Faboya (Members: Late Prof. T.I. Raji, Late Prof. R.O. Ayeni, Prof. A.B. Afolabi, Prof. J.K. Oloke, and Prof. N.O. Olawore), I was offered appointment as a graduate assistant in September, 1998.

Sooner, I had to start postgraduate training, of which I obtained form to study M. Sc. Microbiology programme at the University of Ibadan and I was offered admission. However, I didn't take up the offer, because I was persuaded by the richness of the curriculum for M. Tech Biotechnology that was just developed in the Department of Pure and Applied Biology, LAUTECH, Ogbomoso. So, I offered to stay back, to explore the challenging and stimulating terrain of biotechnology. It paid off as I

finished the programme on record time and obtained distinction in 2001 with lots of experiences garnered along the path of industrial and agricultural biotechnology through the microbial production of ammonia-based biofertilizer that was tested on maize (Lateef, 2001). The thesis was supervised by Prof. J.K. Oloke and examined by Late Prof. A.O. Alabi of the University of Ilorin, Prof. G.O. Oyediran and Prof. M.A. Akinloye with Prof. O.O. Fawole as Chairman of the panel.

Having completed the M. Tech programme, I registered for Ph.D under the supervision of Prof. J.K. Oloke, and within two years I was able to present outcome of my investigations on food grade oligosaccharides in 2003, before I left for the prestigious Central Food Technological Research Institute (a UN institution) at Mysore, India in 2004 for advanced works on fermentation technology, biocatalysis, enzyme technology, bioengineering and instrumentation under the supervision of Dr. Siddalingaiya Gurudutt Prapulla (Rtd). I came back in 2005 to defend my Ph.D thesis on microbial synthesis oligosaccharides, thus stamping my authority as a microbiologist and biotechnologist.

It was fate that brought me in contact with Dr. Prapulla. I photocopied one of her review papers on oligosaccharides at IITA library, Ibadan in 2002 (Prapulla *et al.,* 2000), which served as the basis of my Ph.D work. Preliminary results that were obtained in my work was published in a journal in India in 2003 (Lateef and Oloke, 2003a), which she later told me that the manuscript was sent to her for review. So, it was more than a coincidence when she received my communication seeking for placement in her laboratories as CSIR-TWAS postgraduate fellow. I would forever be grateful to her for the hospitality

and quality mentoring. I produced a report on the microbial synthesis of fructooligosaccharides using *Aureobasidium pullulans* (Lateef, 2005a). My Ph.D work on the microbial production of food-grade oligosaccharides (Lateef, 2005b) criss-crossed microbiology, biotechnology, food science, and biochemical engineering, and was examined by a biochemical engineer, Late Prof. S.K. Layokun of the Department of Chemical Engineering, OAU, Ile-Ife. At various times, Professors O.O. Fawole, A. Olajire, S.O. Jekayinfa and B.I.O. Ade-Omowaye served as members of panels. The panels were chaired by the current deputy Vice-Chancellor, Prof. M.O. Liasu.

My exploit in nanotechnology started lately in 2014, after I was persuaded by my friend, Prof. M.A. Azeez who was on a postdoctoral fellowship at the University of Pune, India to carry out investigations in the area. I took to his advice, despite my tight schedule of shuttling between Departments of Pure and Applied Biology, and Science Laboratory Technology (where I was acting Head of Department). I recruited one of my excellent M. Tech students, Mr. I.A. Adelere (now lecturing at Federal University of Technology, Minna) to incorporate it as part of his thesis. It would turn out to be the first aspect of the thesis to be published. Not minding the challenges faced through lack of facilities for advanced characterization of nanomaterials and the apathy (sometimes denial) towards nanotechnology research, we have remained undaunted to be recognized as key players in nanotechnology even beyond the shores of Nigeria.

Thus, I have trained and re-trained myself in the art of nanoscience, nanotechnology and nanobiotechnology to collapse the seemingly tall and insurmountable barrier between life sciences and materials science for the

advancement of knowledge and service to mankind. It is the story of my contributions in microbiology, biotechnology and nanobiotechnology that I am here to tell the audience; in a language that would not be too technical for us to understand and not too insipid to lose the essence of scientific presentation.

3.0 Microbiology

Microorganisms are living organisms that are very small in size, which cannot be seen with unaided eyes (Figure 1). They are therefore said to be microscopic, indicating a need for them to be magnified before they can be seen. This can be done using magnifying lenses or combinations of such. The study of these organisms was pioneered by a Dutchman, Anton Van Leeuwenhoek in 1667, the father of microbiology; when he used the microscopes that he invented to examine samples of living and non-living things, which could magnify up to 266 times (van Zuylen, 1981) (Figure 2). He was surprised to have seen tiny objects in those samples (Leeuwehoek, 1753; Lane 2015). He called them '*small animalcules*'. This subject is what is termed microbiology. Therefore, microbiology (Greek, *micros = small, bios = life, logos = science)* is the study of minute living organisms called microorganisms. It involves the study of bacteria, fungi, viruses, algae, actinomycetes and protozoans.

In the beginning, microbes were discovered to be responsible for causing diseases, putrefaction and fermentation. All these stemmed from the works of notable scientists such as Robert Koch and Louis Pasteur (Ullmann, 2007). However, at the turn of 19th century, with the advent of sophisticated microscopes and general increase in the body of knowledge, more detailed studies about microbes

revealed that they can serve useful purposes to mankind. These led to developments in industrial microbiology and biotechnology (Buchholz and Collins, 2013).

Figure 1: Different types of microorganisms

"I've spent more time than many will believe [making microscopic observations], but I've done them with joy, and I've taken no notice those who have said why take so much trouble and what good is it?"

Antonie van Leeuwenhoek

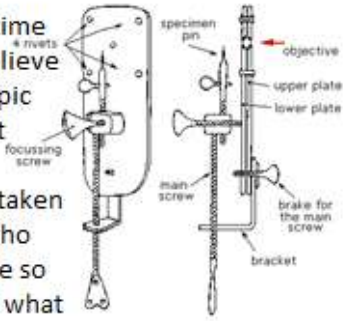


Figure 2: Anton Van Leeuwenhoek (The father of Microbiology)

It is now clear that microbes have useful applications in all facets of human endeavor; despite the huge burden that they constitute to man. To this end, whole cells of microbes or their metabolites such as enzymes, organic

acids, amino acids, polyhydroxylbutyrates, biosurfactants, volatile organic compounds, antibiotics, pigments among others have been applied in different areas to render goods and services for mankind (Demain, 2007).

Some microbes termed probiotics are deliberately consumed to improve the physiological well-being of the consumers (Isolauri *et al.,* 2004). These include *Streptococcus thermophilus, Lactobacillus casei,* and *Bifidobacterium bifidus.* In 2016, the global market for probiotics was worth $36.6 billion, and BCC Research (2018a) estimated that it would be valued at $57.2 billion by 2022. Other microbes that are very rich in proteins such as *Aureobasidium pullulans, Saccharomyces cerevisiae, Candida utilis,* and *Spirulina platensis* are termed as single cell proteins (SCPs) and are also consumed as supplements as replacement for animal proteins (Litchfield, 1983; Ritala *et al.,* 2017), with the market share predicted to reach $8.7 billion by 2023 (Research and Markets, 2018). There are also microbes that ordinarily should not affect us in any manner (except in cases of opportunistic infections and in immunologically compromised conditions), the commensals, such as *Staphylococcus epidermidis.*

Therefore, microbes are necessary evil that man must live with to advance his course on earth. In commerce, microbial-enhanced processes for the production of different products run into hundreds of billions of dollars. For instance, the world production of enzymes, organic acids and alcohols through microbial fermentation stood at $41.568 billion in 2012 (Chadha, 2019) and expected to reach $63.371 billion in 2020 at annual growth rate of 5.4%. In India, $125 million was generated from sales of fermentation products in 2015 (Chadha, 2019). Thus, microbiology is a major participant in global industry and

will be a major player in the new bioenergy industry, hopefully to replace petroleum within the next 30 years.

Today, microbiology is studied in different areas that seek to interrogate the roles of microbes in the environment with practical applications in agriculture, engineering, medicine, biotechnology and so on (Maloy and Schaechter, 2006). Such cosmopolitan investigations have led to sub-disciplines of soil, industrial, medical, petroleum, food, environmental, pharmaceutical, and agricultural microbiology as areas of practice. Its other branches include microbial physiology and metabolism, microbial genetics and molecular biology, microbial immunology, analytical and diagnostic microbiology, virology, mycology, bacteriology, algology, and parasitology.

Since the advent of early man on the earth, ways have been sought towards improving the quality of life; to fight diseases, increase life expectancy and create new range of products to meet human daily needs. In the quest for modernization, man has utilized many tools to achieve quality and healthy living; including the use of biological objects. Today, the use of biological objects, their parts or metabolites to render goods and services for mankind has given birth to a new branch of life sciences; which is biotechnology (Buchholz and Collins, 2013). Therefore, growth and development of any nation and indeed the whole world cannot be discussed without reference to contributions from biological objects (plants, animals and microbes). In this connection, man has utilized several microorganisms in a positive manner (Table 1).

Within the context of development, man has modified the ecosystem in different ways with its attendant consequences including the creation and dissemination of drug resistant microbes, pollution, environmental

degradation, bioterrorism, desertification, and instigation of global warming that encourages multiplication of pathogenic microbes to cause conflict between man and the environment (Ramlogan, 1997). Thus, man stands on the brink of health cataclysm of transnational dimension due to the modification of the ecosystem over time.

Table 1: Some of the applications of microorganisms

S/N	Sector/areas	Applications
1	Agriculture	Biofertilizers, *Rhizobium* inoculants, nutrient cycling, microbial insecticides
2	Pharmaceutical	Antibiotics e.g. Penicillins; useful metabolites e.g. growth factors, amino acids, steroids
3	Environment	Biodegradation & bioremediation of organic matters, industrial effluents & xenobiotics
4	Waste conversion	Waste to wealth e.g. organic fertilizers; use of organic wastes in mushroom production
5	Fossil fuel	Microbial enhanced oil recovery
6	Industries	Enzymes as organic catalyst; organic acids e.g. citric acid; flavours
7	Food	Fermentation processes e.g. yoghurt, cheese, bakery products, *garri*, *fufu*, *iru*, *ogi* etc., starter cultures, sweeteners; food additives e.g. Xanthan gum, biopreservatives e.g. nisin & bacteriocin; single-cell protein
8	Drinks	Fermentation to produce alcoholic & non-alcoholic drinks
9	Healthcare	Vaccine production, healthy foods (nutraceuticals), prebiotics, probiotics
10	Solid minerals	Recovery of metals, bioleaching & biomining
11	Renewable Energy	Renewable energy; biogas, bio-hydrogen, biodiesel & microbial fuel cells.
12	Diagnostics/ analytical	Biosensors, enzymes as analytical reagents e.g. GOD-POD for glucose determination
13	Forensics	Taq polymerase for DNA amplification; endonucleases, ligases etc.
14	Bioeconomy	Starter culture, enzymes, citric acid, biosurfactants, single cell proteins

As a key component of biological resources, microbes must be handled with utmost care. Therefore, man, microbes and development are intertwined in such an intricate manner that must be well understood, for man to ensure healthy living on earth.

3.1 Biotechnology

Biotechnology though can be defined in several ways; however my preferred definition is 'the use of biological resources (whole cell, parts, metabolites or genetic resources) to render goods and services for mankind'. It is viewed as exploitation of bioresources by man. It can be divided into two components; traditional biotechnology and modern biotechnology (Table 2). While traditional biotechnology is as old as man, modern biotechnology that deals with the genetic manipulations of organisms is of recent advent (Okafor, 2007). Man has practiced biotechnology in the forms of plant and animal cross-breeding, grafting, fermentation (production) of foods, condiments and drinks such as *garri, fufu, iru, ogiri, lafun, tempeh,* yoghurt, *ogogoro, burukutu, nunu,* bread etc.

Without microorganisms, fermentation processes are impossible, because microbes with the retinue of enzymes breakdown the complex organic molecules and convert them into the final products with new qualities and value addition (Steinkraus, 2002). Among several things, fermentation can be employed to achieve food safety and security through preservation (lowering of pH by producing organic acids that limit the proliferation of putrefactive organisms and antimicrobial factors like bacteriocin and nisin), improved nutritional quality (protein enrichment), detoxification (removal of anti-nutritional factors and toxic principles), improved consumer appeal (enhanced

digestibility and flavouring) and production of nutraceuticals to promote physiological well-being to fight debilitating disorders including obesity, cancer and arteriosclerosis.

Table 2: The types of biotechnology

Type	Other names	Nature	Examples
Traditional	Low-level	Old (since ancient times), low technology, simple, & low-cost	Production of enzymes, fermented foods (*garri*, *iru*, *fufu*), sewage treatment, biogas, mushroom cultivation, cross breeding of plants and animals for desirable characters, biofertilizers (*Rhizobium* inoculant, compost, mycorrhizae), biopesticides, SCP, algal technology (*Spirulina platensis*), tissue culture
New	Modern biotechnology, rDNA Technology, Cloning, Genetic engineering, molecular biology.	Relatively new (started in 70's), complex, capital intensive, involves manipulation of genetic material.	Creation of transgenic plants and animals, and recombinant microbes for diverse applications, gene therapy, GM foods, probes, markers, drug discovery, forensics, genomics, diagnostics, biochip

In addition to application in food production, fermentation can be employed to produce a number of products of immense use to man. For instance, citric acid production is the exclusive preserve of a fungus, *Aspergillus niger* (Show *et al.*, 2015) which has been used since 1919 (Schuster *et al*, 2002) with world production that exceeded 2 million tons in 2018 and worth $2.545

billion (BCC Research, 2020). Wide ranges of products that listed in Table 1 are produced through fermentation by microbes for various applications, with enourmous contributions to the world's economy. The global market for bioproducts should reach $714.6 billion by 2021 from $466.6 billion in 2016 at a compound annual growth rate (CAGR) of 8.9%, from 2016 to 2021 (BCC Research, 2017a).

Modern biotechnology, variously referred to as molecular biology, cloning, recombinant DNA technology or genetic engineering utilize wide range of techniques to manipulate the genetic constituent of an organism in such a way that the genetically modified organisms (GMOs) depict new set of attributes that are not known to the natural forms (wild type) of the organisms. Through this technology, transgenic plants and animals and recombinant microbes have been created with unique properties (Demain and Vaishnav, 2009). For instance, golden rice with the ability to synthesize β-carotene, the precursor for the synthesis of vitamin A to forestall vitamin A deficiency among consumers of rice has been produced (Beyer *et al.*, 2002). Also, *Bt*-cotton that has the ability to produce δ-endotoxin of entomopathogenic *Bacillus thuringiensis* has been produced with the ability to prevent insect infestation of the crop, thereby reducing the use of insecticide (Lu *et al.*, 2012).

Through modern biotechnology, a bacterium, *Escherichia coli* can be used to produce human insulin for diabetic patients (Schmidt *et al.*, 1999) with the world production valued at $26.64 billion in 2016 (BCC Research, 2018b). Similarly, plants with vigour, tolerance to environmental stresses, improved yield, enhanced nutritional qualities, and shorter life cycle have been

created to combat hunger and food insecurity (Rani and Usha, 2013). Nigeria has recently licensed the commercial production of genetically modified pod borer-resistant cowpea (PBR Cowpea)-event AAT709A, genetically improved to resist *Maruca vitrata* (responsible for 70-90 yield loss) (IITA, 2019; Nigerian Tribune, 2019). Cultivation of the improved GM cowpea would reduce spraying with insecticides from eight to two with yield expected to increase by 20%. Nigeria is projected to earn $132 million annually from the cultivation of the *Bt* cowpea which has been found to be safe for both human and animal consumption (IITA, 2019).

Biotechnology is a multidisciplinary field of study (Figure 3). A biotechnologist can utilize techniques derived from chemistry, microbiology, biochemistry, chemical engineering and computer science. Chemical engineering and biochemistry are two well recognized examples of disciplines that have done much to clarify our understanding of chemical processes and the biochemical bases of biological systems, while advances in computer science are exploited in the monitoring and control of fermentation processes as well as computational analysis of data. Of course, microbiology is the bedrock of biotechnology with several microbes involved in the fermentation processes, and microbes being the sources of enzymes and vectors of gene transfer that are used in genetic engineering protocols (Demain and Adrio, 2008).

The main objectives are innovation, development and optimal operation of processes in which biochemical catalysis has a fundamental and irreplaceable role. Biotechnologists must also aim to achieve a close working cooperation with experts from other related fields, such as medicine, nutrition, the pharmaceutical and chemical

industries, environmental protection and waste process technology. Biotechnology has two clear features: practical applications and interdisciplinary cooperation. Table 3 summarizes different applications of biotechnology using the colour coding system.

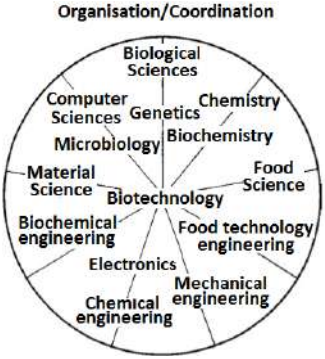


Figure 3: The interdisciplinary nature of biotechnology

Table 3: Applications of biotechnology using the colour coding system

Colour	Applications
Red	Health, medical, gene therapy, regenerative medicine, vaccines and antibiotics, developing new drugs, molecular diagnostics techniques
Yellow	Food biotechnology, nutrition science
Blue	Aquaculture, coastal and marine biotechnology
Green	Agricultural, biofertilizers, biopesticides, transgenic plants & animals
Brown	Arid zone and desert biotechnology
Dark	Bioterrorism, biowarfare, biocrimes, anticrop warfare
Purple	Patents, publications, inventions, intellectual property rights
White	Gene-based bioindustries, biocatalysis, enzymes, chemicals, design and production of new materials for daily use
Grey	Environmental biotechnology, biofuels, bioremediation, geomicrobiology
Gold	Nanobiotechnology, bioinformatics, computational biology

3.2 Nanotechnology

Nanotechnology is the art of creation, manipulation, investigations and applications of materials at the nanoscale (10^{-9} m or 1 billionth metre). It is in the core area of materials science, which had its origin from the lecture delivered by Prof. Richard Feynman in 1959 (Hulla *et al.*, 2015). Feyman, a physicist and 1965 Nobel Laureate in his lecture titled "*There's Plenty of Room at the Bottom*", at the meeting of American Physical Society at Caltech, USA introduced the concept of manipulating matter at the atomic level (Feynman, 1960). He queried if it would be possible to put the 24 volumes of Encyclopedia Britannica on the head of a pin. This novel idea demonstrated new ways of thinking and Feynman's hypotheses have since been proven correct. It is for these reasons that he is considered the father of modern nanotechnology.

However, it was a Japanese scholar, Prof. Norio Taniguchi of Tokyo Science University, Tokyo that first used the term 'nanotechnology' in 1974 to describe semiconductor processes occurring at nanometer (Taniguchi, 1974). Further, leveraging on the contributions of Feynman and Taniguchi, Prof. Eric Drexler of Massachusetts Institute of Technology (MIT), USA brought in the golden era of nanotechnology in 1986 in his book titled 'Engines of creation: The coming era of nanotechnology', where he proposed the idea of nanoscale 'assemblers' (Drexler, 1986) that laid the foundation of molecular nanotechnology. These three scholars are recognized as champions of nanotechnology (Figure 4).

The fundamental issue about nanomaterials having dimensions in the range of few nanometers is how they differ from their bulk precursors. However, the changes in optical, electrical, biological, photothermal, physical and

chemical properties have been linked to their improved surface area to volume ratio that enhances their reactivity (Figure 5).

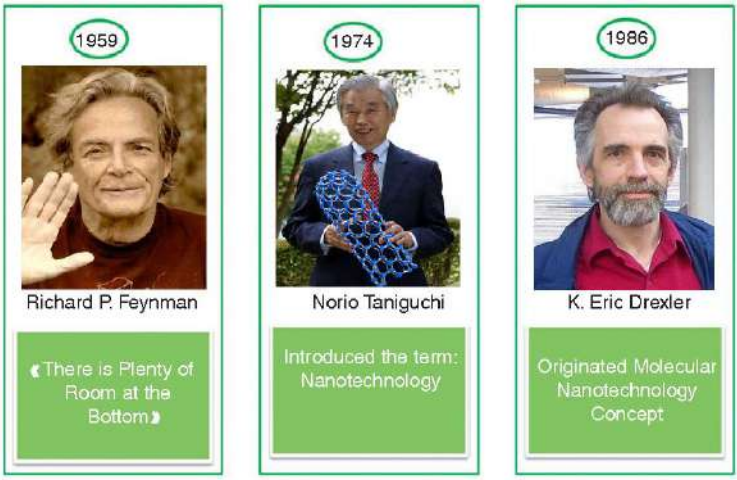


Figure 4: The heroes of nanotechnology

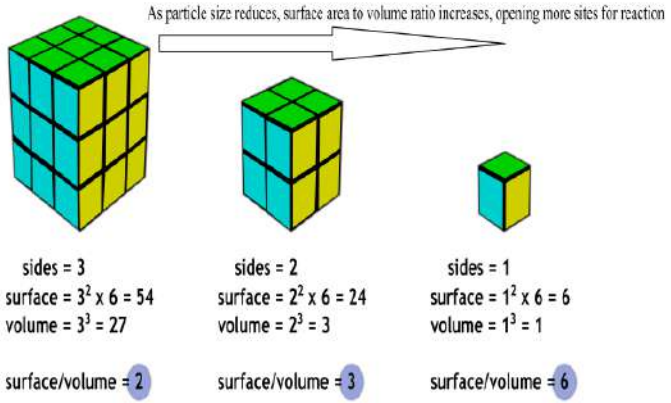


Figure 5: Relationship between sizes of particles and surface area to volume ratio

Nanomaterials are of various types; natural and man-made. The examples of natural materials of nanoscale dimensions include fine dust, volcanic ash, viruses and DNA. However, several nanomaterials can by synthesized via physical, chemical and biological methods. The engineered or synthetic nanomaterials as shown in Figure 6 can be inorganic (metal and metal oxide nanoparticles), organic (liposomes, dendrimer) and carbon-based (Graphene, fullerenes, Quantum-dot, carbon nanotubes).

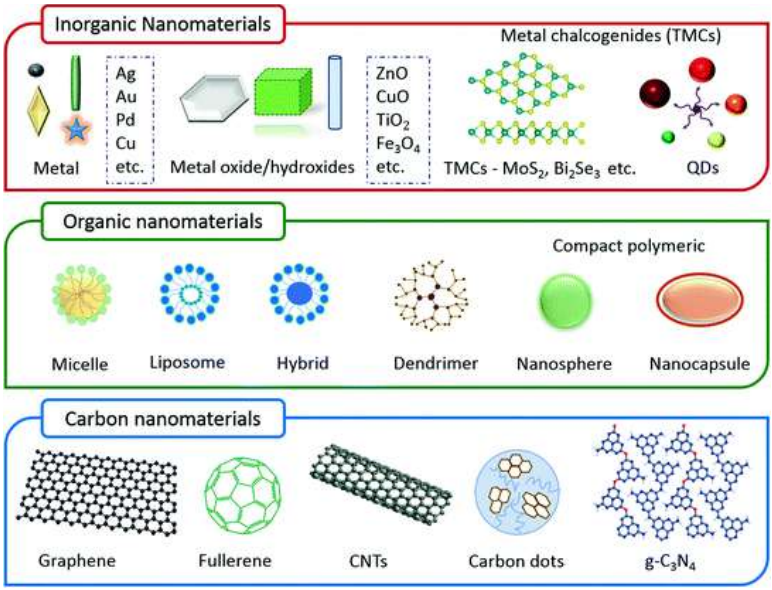


Figure 6: Examples of engineered nanomaterials

In the last four decades, several novel nanomaterials have been produced for application in different areas of human endeavours (Table 4), ranging from agriculture, medicine, engineering, environment and consumer services.

Table 4: Some important applications of nanomaterials

S/N	Sector	Applications	Nanomaterials
1.	Agriculture	Pesticide, fertilizer, tissue culture	AgNPs, TiONPs, ZnONPs
2.	Environment	Degradation and adsorption of pollutants	AgNPs, TiONPs, ZnONPs
3.	Food	Antimicrobials, preservation, packaging, nutrient enhancement and bioavailability	AgNPs, TiONPs, ZnONPs, MgONPs, CaONPs
4.	Energy	Solar panel, super capacitors, fuel cells	AgNPs, TiONPs, ZnONPs, AuNPs, CNTs, graphene
5.	Healthcare	Antimicrobial, imaging, drug-delivery, tissue engineering, anticancer, antioxidant, antidiabetic, wound healing, dentistry	AgNPs, TiONPs, ZnONPs, AuNPs, graphene, CaONPs, dendrimer, liposomes, CNTs
6.	Engineering	Electronics, smart appliances, construction, novel material composites	AgNPs, TiONPs, ZnONPs, AuNPs, graphene, CNTs, SiONPs
7.	Water	Treatment and purification	AgNPs, TiONPs, ZnONPs, AuNPs, graphene, CNTs, Nanoclay
8.	Consumer products	Antimicrobial, anti-aging, sunscreen, UV-shielding, lightness and improved strength, fire-retardant, preservative	AgNPs, TiONPs, ZnONPs, AuNPs, graphene, CNTs
9.	Defense and security	Antimicrobial, water repellant and self-cleaning, exceptional strength	AgNPs, TiONPs, ZnONPs, AuNPs, graphene, CNTs
10.	Industries & analytics	Nanocatalysts, sensors, fuel-cell catalyst, anti-corrosion, oil-drilling, composites	PtNPs, TiONPs, ZnONPs, PdNPs, graphene, CNTs, AgNPs, AuNPs

Nanotechnology is contributing to the world's economy (Table 5) and its adoption has led to production of novel materials, and rendering of specialized services, with the projection that by 2020, about 2 million workers in the US would have nanotechnology-related jobs, and the US market value of nano-products would be $1 trillion, or 5 % of the GDP of US (ACS, 2020). It was projected that the world market of products containing nanomaterials would be $2.6 trillion in 2015 (Raj *et al.*, 2012).

The beauty of nanotechnology as it is with biotechnology is its cosmopolitan nature in both practice and application. Everyone can have a bite of the cake as '***There's Plenty of Room at the Bottom***'.

Table 5: Contributions of nanotechnology to the World's economy

S/N	Sector, product or application	Worth (USD billion) and year	References
1.	Energy	5.7 (2018)	BCC Research (2019)
2.	Medical	151.9 (2017)	BCC Research (2017b)
3.	Printing technology	14.0 (2013)	BCC Research (2014b)
4.	Environment	23.4 (2014)	BCC Research (2015)
5.	Nanomachines and devices	0.736 (2017)	BCC Research (2018c)
6.	Drug development and delivery	29.6 (2014)	BCC Research (2014c)
7.	Silver nanoparticles	1.3 (2017)	Global Market Insights (2018)
8.	Gold nanoparticles	1.3 (2014)	Global Market Insights (2014)
9.	Titanium dioxide nanoparticles	3.4 (2014)	Allied Market Research (2014)
10.	Graphene	0.0428 (2017)	Grand View Research (2019)

Series of data have shown steady rise in the number of articles published in nanotechnology, number of patents and investment by several countries.

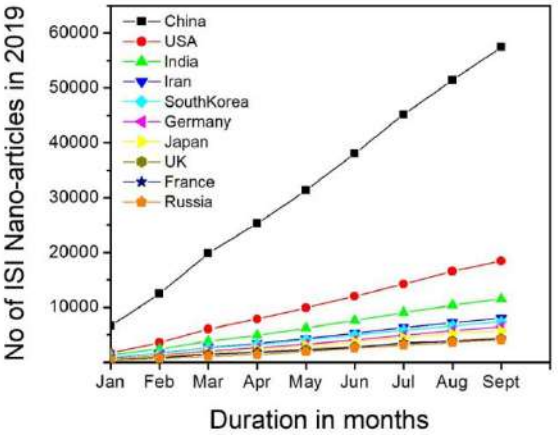


Figure 7: Number of ISI nano-articles published in 2019 by 10 leading countries in nanotechnology (ISI, 2019)

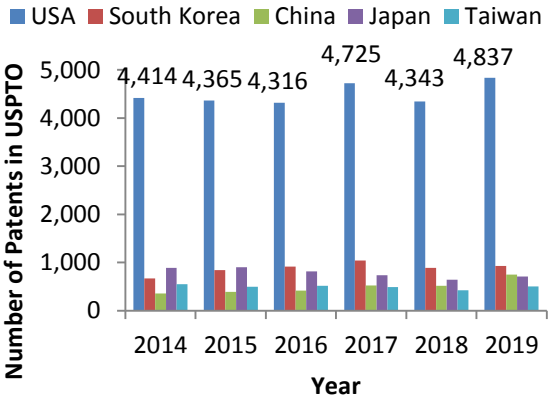


Figure 8: Number of patents in nanotechnology in USPTO by five leading countries in nanotechnology (STAT NANO, 2020a)

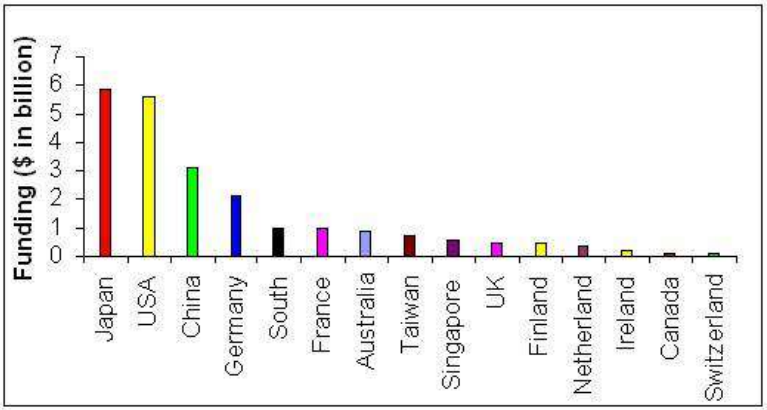


Figure 9: Investment in nanotechnology by different countries from 2006-2010 (Nanotechnology Now, 2010)

It can be deduced from these data that the major players in nanotechnology are advanced countries of the world, notably US, Japan, Germany, South Korea, France, UK and Russia. Other countries like China, Taiwan, India, and Canada also featured prominently in patent filing and manufacturing of nano-based products. However, Africa lags behind with Egypt and South Africa having some sorts of investments in nanotechnology, policy on nanotechnology development and fair contributions to nanotechnology outputs (patents and publication).

Nigeria's status in nanotechnology is abysmal, without any patent in USPTO, almost no budget heading or investment in nanotechnology, low-level of publications, low-level of public awareness about nanotechnology, deficiency of curricula of science and technology courses in nanotechnology, and dearth of experts in nanotechnology among others (Batta *et al.,* 2014; Elegbede and Lateef, 2019a). For instance, nano-article per million people in Nigeria in 2017 was just about one article, indicating

contribution of less than 200 articles on nanotechnology and there was no patent in USPTO and EPO in the coverage period of 2015-2019 (STAT NANO 2020b). There is also dearth of equipment necessary to carryout nanotechnology research in Nigerian institutions as well as lack of centre of excellence in nanotechnology, and regulatory agency on nanotechnology. A comparative analysis of Nigeria and South Africa in nanotechnology R&D is presented in Table 6. Unlike in Nigeria, where there is no dedicated fund for nanotechnology research, South Africa has streams of fund specifically for nanotechnology. These include nanotechnology flagships project (NFP) for emerging researchers, and national nanotechnology equipment programme (NNEP) to support researches and procure state-of-the-art equipment (NRF, 2015).

Table 6: Comparative performance of South Africa and Nigeria in nanotechnology R&D

Indices	South Africa*	Nigeria**
Articles per million people	16.51	1.36
No. of nano-based products	14	0
No. of nano-companies	9	0
Patents in USPTO (2015-2019)	20	0
Nanopatents per 100 articles	1.06	0
Nanotechnology standards	11	0
ISI-indexed nano-articles in 2019	1151	408
Agency on public engagement	Yes, NPEP	No
Priority funding of nano-research	Yes; NRF[#]	No
National strategy on nanotechnology	YES, NNS	Yes, NIN but moribund

*STAT NANO (2020c); **STAT NANO (2020b); NPEP, Nanotechnology public engagement programme (https://www.npep.co.za/about-npep/); [#]NRF (2015); NNS, National nanotechnology strategy; NIN, National initiative on nanotechnology.

3.3 Microbiology, Biotechnology and Nanotechnology: The Nexus and a Worthy Enterprise

Nanomaterials are generally produced through two approaches; top-down, and bottom-up (Figure 10), where larger molecules are broken down to nanomaterials and atoms are built-up to form nanomaterials, respectively.

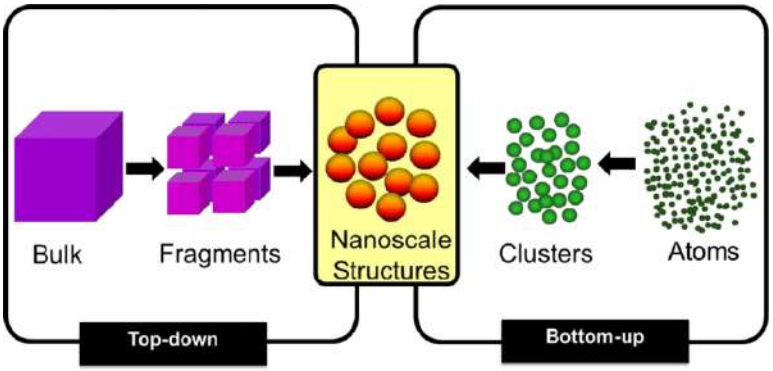


Figure 10: Top-down and bottom-up approaches in the fabrication of nanomaterials (Rawat, 2015)

Both physical and chemical techniques have been used to fabricate nanomaterials and these include high energy ball milling, sintering, melt mixing, sol-gel, inverse micelles, laser ablation, sputter deposition, electric arc deposition, chemical vapour deposition, hydrothermal, sonication, and irradiation among others. However, these techniques are plagued with consumption of high energy, high cost of production, complexity in reaction, and non-ecofriendly and toxic procedures.

These drawbacks can be avoided through greener synthesis using biological materials that are rich in biomolecules for the catalysis of formation of

nanomaterials through bottom-up approach. The green process also termed biosynthesis, biomimetic, biogenic, bio-inspired or green synthesis is an economical process, simple, rapid, facile, eco-friendly, environmentally-benign and often yields more biocompatible nanomaterials that are devoid of toxic principles (Agarwal *et al.*, 2017; Sharma *et al.*, 2019). In this connection several biological materials and biomolecules derived from plants, bacteria, fungi, algae, actinomycetes, insects, animals have been utilized to produce nanomaterials for diverse applications (Golinska *et al.*, 2014; Yadav *et al.*, 2015; Lateef *et al.*, 2016a; Sharma *et al.*, 2016; Singh *et al.*, 2016).

While the synergy between microbiology and biotechnology is well established, we may begin to wonder if such relationship exists between microbiology and nanotechnology. For ease of explanation, the relationship between microbiology and nanotechnology can be summarized as follows:

i. Several microbes, particularly bacteria, fungi and algae have immense abilities to tolerate, sequester, accumulate and detoxify metals through series of redox reactions. These attributes have made them to be useful tools in the microbial remediation of metal-polluted soils and wastewaters, and for exploitation in the recovery of precious metals such as silver, copper, gold, lead and zinc via biomining and bioleaching in the fields of geomicrobiology and geobiotechnology. Thus, there is special relationship between microbes and metal in terms of uptake, processing, utilization and cycling in nature. Economic viability of bioleaching of metals from polymetallic ore using bacteria has been demonstrated (Kržanović *et al.*, 2019).

ii. In the bid to detoxify metals, microbes can use enzymes, proteins and pigments to reduce metal ions to metallic nanoparticles, which can then be accumulated within the cell or excreted out of the cell. Thus, either intra- or extracellularly, microbes can serve as cell factories to reduce various metals to zero valent species; which is the hallmark of the microbial synthesis of metallic nanoparticles (Mandal *et al.*, 2006).

iii. Conversely, metallic nanoparticles have been proven to have biocidal actions on bacteria, fungi, algae, protozoans and viruses. The biocidal activities of the particles are attributed to the generation of free radicals, reactive oxygen species, and denaturation of macromolecules such as proteins, enzymes and DNA amongst others (Durán *et al.,* 2016). The particles can also serve as carrier of drugs into the cell with improved surface area of activity (Ng *et al.,* 2014), and also act in synergy with antimicrobial drugs (Allahverdiyev *et al.,* 2011). The use of nanoparticles in combating the scourge of multidrug resistant microbes is well documented in literature (Zielińska-Górska *et al.,* 2017). The multiple actions of nanoparticles have placed them at an advantage over antibiotics in suppressing resistance mechanisms among microbes. As such, nanoparticles have found diverse applications as coating materials to prevent microbial growth and survival (for instance in surgical instruments and textiles), filters for the purification of water, as additives in paints to prevent microbial deterioration (Voegele *et al.,* 2008; Pradeep, 2009; Bellotti *et al.,* 2015; Perelshtein *et al.,* 2015) and packaging materials in food industries (Espitia *et al.,*

2012). The global market of nanoparticles in biotechnology and pharmaceutical was put at $25 billion in 2013, and projected to reach $79.8 billion in 2019 (BCC Research, 2014a).

iv. In bioprocess development, it has been established that supplementation of growth media with nanoparticles (albeit at low concentrations) instead of the bulk form of metals (salts) can cause metabolic perturbation in microbes, thereby improving the performances at producing novel products (Sanusi *et al.,* 2019). Recently, we showed that nickel nanoparticles improved ethanol yield and protein accumulation in *Saccharomyces cerevisiae* (Sanusi *et al.,* 2020), while other studies have shown positive impacts on biogas and biohydrogen yields by bacteria (Sekoai *et al.,* 2019). Some nanoparticles, particularly magnetic particles have also been applied as resin for the one-time purification of microbial enzymes (Zhou *et al.,* 2017). Similarly, nanoparticles have been deployed for the immobilization of enzymes to enhance performance and reusability (Ji *et al.,* 2017). The impact of nanobiotechnology in bioprocess development is an evolving field whose results would not only be stimulating but a paradigm shift in fermentation process that would open new vista of research in microbial physiology and metabolism.

v. Products of microbial transformation can be enhanced in their activities through nanotechnology. For instance, the dispersion of oil in water and leaching of crude oil from soil matrix by microbial surfactants can be enhanced by surfactant-nanometal hybrid (Amani 2017), which may lead to the development of novel nano-based biosurfactant for enhanced oil recovery,

especially from marginal fields. Nanoparticles have also shown to enhance microbial transformation of xenobiotics (Zhang *et al.,* 2011) to control pollution.

From the foregoing, it can be established that nanotechnology is of relevance to microbiology in the areas of microbial synthesis of nanoparticles, control of growth of microbes by nanoparticles and utilization of nanoparticles to improve the performance of microbes in fermentation processes to produce novel products. Nanomaterials are also important components of downstream process in fermentation for the recovery of products. In totality, there is concordance among the tripartite fields of microbiology, biotechnology and nanotechnology.

Further, the union of biotechnology with nanotechnology birthed nanobiotechnology, which belongs to the section of 'gold biotechnology' as earlier presented in Table 2. This exposition lay to rest the argument about impropriety of foray of a microbiologist in the field of nanotechnology, as there is convergence between the two disciplines (Khanday, 2018). In actual fact, nanotechnology has been recommended as a novel tool for microbiologists to advance their research activities (Orth *et al.,* 2016). However, much is still needed to be done to elucidate the impacts of nanomaterials on microorganisms in terms of physiology, metabolism and genomics.

3.4 Is there any Gap in Knowledge between Microbiology and Nanotechnology?

The seemingly apathy of microbiologists to developments in nanotechnology is rooted in '*nanophobia'* which pervades several other disciplines in the sciences.

Nanotechnology is often viewed as an area of research that is reserved exclusively for the experts in materials science, solid state physics and engineering fields. While nanotechnology has its roots in physics, it has extended its tentacles to allied fields. Today, it is at the interface of physics, chemistry, and materials science, thus necessitating that any serious investigation in the field would require some modicum of knowledge in the aforementioned areas. This requirement poses some constraints to many microbiologists; thereby limiting their engagements in nanotechnology research.

The challenges can be addressed through collaboration whereby nanotechnology-related researches could be executed by postgraduate students in order to train them and stimulate their interests in nanotechnology to produce new crops of microbiologists with proficiency in nanotechnology. Similarly, advanced studies on the interactions of microorganisms with nanomaterials should be vigorously pursued to open up new lines of researches.

Secondly, there is limited exposure of microbiologists to nanotechnology as both undergraduate and postgraduate curricula of microbiology lack coverage of materials science and nanotechnology (Elegbede and Lateef, 2019a). Therefore, to solve this problem, microbiology curriculum must be re-engineered to accommodate discourse on nanotechnology. Worldwide, there are limited textbooks on microbial nanotechnology and the concept of nanotechnology in microbiology (Rai and Duran, 2011), although there are excellent reviews on specific aspects of nanotechnology in microbiology and vice-versa (Zhang *et al.*, 2011; Natan and Banin, 2017; Carvalho *et al.*, 2018; Kerry *et al.*, 2018).

Therefore, top researchers at the frontiers of microbiology and nanotechnology have the responsibility to evolve curriculum that would integrate principles and applications of nanotechnology into microbiology, and also produce reading texts for the budding microbiologists. These are parts of my vision as a microbiologist, biotechnologist and nanobiotechnologist.

4.0 My Research Activities

In September 1998, I was employed as a graduate assistant in the Department of Pure and Applied Biology, LAUTECH; and having received sound training from my teachers, it was not difficult for me to solve some research problems. These, I have been doing till now. My research efforts can be summarized as follows:

4.1 Formulation of Biofertilizer

The potentials for the improvement of biological production of ammonia by manipulation of microbial metabolic fluxes through medium formulation were elucidated in my master thesis. The study underpinned the possibility of alternative source of ammonia to curb the growing cost of production of nitrogen fertilizers. Overproduction of ammonia by strains of *Staphylococcus aureus* and *Pseudomonas* were established (Gueguim-Kana *et al*., 2001; Lateef, 2001; Lateef and Oloke, 2002; Lateef *et al*., 2003a). Ammonia yield of 13.09 mg/ml was produced by *S. aureus* in fish hydrolysate, while *P. aeruginosa* yielded 15.61 mg/ml of ammonia in meat peptone.

Biofertilizer which was a constituent of aqua ammonia and cocoa pod ash filtrate (as source of potassium) was formulated and tested on two varieties of maize (*Zea mays*).

The performance of the biofertilizer was significantly better than the control, while it compares favourably with the NPK fertilizer in terms of the number and weight of the maize grains. Furthermore, the biofertilizer increased the percentage nitrogen composition of the soil at harvest by 44% in relation to the control. The study emphasized the economic benefits of ammonia-based fertilizer.

4.2 Microbiology of Water

Water is a valuable resource material for the survival of all life forms in the ecosystem (Rahaman and Varis, 2005). Its quality and availability are prime requirements in the society. Thus, efficient microbiological control is essential for the implementation of good management of this vital resource. In Nigeria, water is sought from different sources which include rainfall, streams, rivers, wells and boreholes for different use. Also, treated water is made available by water treatment plants (tap water) and packaged water (sachet and bottled). Irrespective of the source of water, there are basic microbiological requirements of potable water. It is becomes imperative to evaluate the microbiological quality of water to ensure the safety of public health, as several pathogens can survive in water and instigate water-borne diseases such as cholera, dysentery, diarrhoea, typhoid fever, and shigellosis (Hatami, 2013). The microbiological standards of potable water in Nigeria stipulates maximum limit of 10 cfu/ml for total coliform count and complete absence of thermoterant coliform, *E. coli,* faecal *Streptococcus* and *Enterococcus* in 100 ml of water (NSDWQ, 2015).

In this connection, I have conducted several studies, aiming at determining the microbiological safety of drinking water from different sources including; rain, tap,

shallow wells, boreholes, ice and packaged water in Nigeria (Adebisi *et al*., 2002; Fawole *et al*., 2002; Lateef and Yusuf, 2002; Lateef *et al*., 2006; Lateef *et al*., 2012a). These studies established contamination of many of the water and ice samples by microorganisms, and were adjudged not to be fit for human consumption. In evaluating forty-one samples of water from river, tap, rain, well and treated sources obtained in Ogbomoso, bacterial loads of 1.0×10^1-6.0×10^6 cfu/ml were obtained (Fawole *et al.*, 2002). All the water samples were contaminated, but the incidence of *Escherichia coli* ranged from 40 % for sachet to 100 % for river and well water. The rain water was devoid of *E. coli* (Table 7).

Table 7: Comparative analysis of microbiological features of water samples obtained in Ogbomoso metropolis*

Sample	Presence of bacteria	Presence of coliform	Presence of *E. coli*
Rain	100	0	0
Well	100	100	100
River	100	100	100
Sachet	100	40	40
Tap	100	57.14	57.14

*, all values in %

In another study, we evaluated fourteen samples of surface and underground water in Igbeti, Oyo state (Adebisi *et al.*, 2002), with 93% of the water samples contaminated with bacteria, feacal matter and *E. coli*. The most probable number of coliform bacilli/100 ml of water ranged from 6 - ≥1800. We also examined twenty-two samples of NAFDAC-approved sachet water obtained from Ogbomoso, Ibadan and Osogbo (Lateef and Yusuf, 2002). The water samples were of very high microbiological

quality, as only a sample had microbial load of 2.4×10^2 cfu/ml and MPN of 2 with the incidence of faecal coliform and *E. coli.*

In an investigation spanning four months, forty samples of commercial ice used for the cooling of fish and drinks were obtained from small-scale producers of ice in Ogbomoso and examined microbiologically (Lateef *et al.*, 2006). All the samples were contaminated with bacteria (Table 8), had microbial index of 10^4, which exceeded the limits of <500 and $<10^2$ cfu/ml for ice obtained from manufacturing plant and retail outlet respectively (Nichols *et al.,* 2000). Many of the isolates obtained from the ice samples were pathogenic with public health concerns.

Table 8: The attributes of commercial ice samples

Source	Type of ice	Microbial load (cfu/ml)*	Isolates**
A	Bar	1.88×10^4	*Pediococcus cerevisiae, Bacillus subtilis, Streptococcus pyogenes, Bacillus firmus,* and *Pseudomonas aeruginosa*
B	Shaved	2.19×10^4	*Streptococcus equi* and *Bacillus firmus*
C	Cube	3.10×10^4	*S. equi, Staphylococcus epidermidis, S. pyogenes,* and *Micrococcus luteus*
D	Shaved	3.20×10^4	*M. luteus* and *P. aeruginosa*

*, each value is an average of ten samples; **distinct isolates

We have also probed the quality of one hundred water samples obtained from ten boreholes within Ogbomoso metropolis (Lateef *et al.,* 2012a). The physico-chemical attributes revealed that the ammonia, manganese, nitrate, nitrite, fluoride, chloride contents, conductivity and total

dissolved solids were below the permissible levels. However, total alkalinity and total hardness values of some water samples were higher than the permissible levels, while all the water samples had BOD and COD values that were higher than the permissible levels. The microbial quality of the water samples indicates extensive microbial contamination involving heterotrophic bacteria, coliforms, yeasts/molds, staphylococci, and *Shigella*. The cumulative microbial loads of the water samples ranged from 3.14-8.6 $\times 10^3$ cfu/ml (Table 9). Bacteria in the genera *Proteus, Escherichia, Shigella, Streptococcus, Staphylococcus, Bacillus, Pseudomonas, Enterobacter,* and *Klebsiella* were isolated in the study.

Similarly, studies have been conducted on natural bodies of water to determine the level of pollution due to human activities. Studies on Odo-Oba and Oyun rivers showed high level of microbial contamination. Odo-Oba river receives human-induced wastes and leachates from nearby refuse dumps and cassava flake (*garri*) processing centres, run-off from farms, deposition from air as a result of heavy vehicular traffic on Oyo-Ogbomoso road. Twenty-one samples analyzed over a period of seven months recorded microbial loads of 2.5×10^2-9.4×10^4 cfu/ml, with high MPN of $\geq$ 1800, presence of faecal coliforms and *E. coli* (Bakare *et al*., 2003). Similarly, Oyun river in Ilorin, Kwara State had mean microbial loads in the range of 3.83×10^5-7.84×10^5 cfu/ml with MPN of $\geq$ 1800, presence of faecal coliforms and *E. coli* (Adewoye and Lateef, 2004a). Specifically, *E. coli, S. aureus, P. aeruginosa, Klebsiella* sp and *Enterobacter* sp were isolated from the eighteen water samples taken over a period of six months.

Table 9: The microbial loads (× 10^3 cfu/ml) of the water samples from the boreholes*

Source	APC	CC	SSC	STC	MYC	Cumulative microbial load
A	5.26 (10)	2.62 (10)	0	0.2 (4)	0.12 (4)	8.2 (28)
B	4.94 (10)	2.66 (10)	0.02 (1)	0.7 (10)	0.28 (4)	8.6 (35)
C	2.0 (10)	1.8 (10)	0.8 (3)	0	1.0 (7)	5.6 (30)
D	1.8 (10)	1.6 (10)	0.6 (3)	0	0.8 (8)	4.8 (31)
E	1.21 (10)	1.21 (10)	0	0	0.72 (7)	3.14 (27)
F	1.49 (10)	1.62 (10)	0	0	1.37 (8)	4.48 (28)
G	2.2 (10)	1.9 (10)	0	0	0.5 (8)	4.6 (28)
H	1.5 (10)	1.7 (10)	0	0	0.4 (7)	3.6 (27)
I	2.42 (10)	1.24 (10)	0	0.14 (4)	0.14 (4)	3.94 (28)
J	2.48 (10)	1.12 (10)	0	0.18 (4)	0.12 (4)	3.9 (28)

APC, aerobic plate count; CC, coliform count; SSC, *Salmonella-Shigella* count; STC, staphylococcal count; MYC, mould-yeast count; *, microbial load is an average ten readings and has uniform index of 10^3; number in parenthesis indicate the number of positive samples.

Mr. Vice-Chancellor, Sir, results obtained in these studies with the analysis of two hundred and fifty-six samples of water from different sources indicate that 91.80% of the water samples were not fit for human consumption as they did not meet the required microbiological quality (NSDWQ, 2015). However, water obtained from these sources, including the rivers are being used for drinking and other activities by people. Thus, there is the need to prioritize the provision of potable water and popularize sanitation among populace as critical ways of preventing the scourge of water-borne diseases. Suffice to say that available clean water and sanitation is the goal 6 of sustainable development goals. Non-availability of clean water is a global problem. As of 2015, 2.3 billion people

lacked basic sanitation and 844 million people did not have access to clean water (UNDP, 2020).

4.3 Microbiology of Industrial Effluents and Genotoxic Studies

The rapid industrialization in the world is not without consequences. Among the consequences of industrial activities is the discharge of untreated or partially treated industrial wastewaters in the natural water bodies that lower the quality of such water bodies through pollution. Waterways have been shown to receive more than 80% of wastewaters (UNDP, 2020). In the bid to look at microbiological impact of discharge of industrial effluents, industrial effluents from pharmaceutical and detergent industries have been studied with the view of determining their microbiological attributes; and possible genotoxic potentials in *Allium cepa.*

The pioneer study in this area was carried out in 2002, whereby the microbiology of a pharmaceutical effluent collected along its path of discharge was determined (Lateef, 2004). It had microbial load of 2.15×10^5 cfu/ml and there was evidence of faecal contamination with MPN of >1800. The organisms encountered included *S. aureus, E. coli, Proteus vulgaris, Serratia marcescens* and *P. aeruginosa.* We were able to establish that these effluents pose dangers to the environment, aquatic organisms and man. In a study by Lateef and Yekeen (2006), wastewater from metronidazole production of a pharmaceutical had microbial load of 2.15×10^5 cfu/ml, MPN of ≥1800 and presence of *E. coli* and *S. aureus.* The effluent induced various types of chromosomal aberrations (sig. at $p < 0.05$), while the mitotic inhibition ranged from 35.33 to 69.76% at tested concentrations of 0.1-10%. The EC_{50} of root growth

inhibition was obtained as 9.3%, indicating its moderate toxicity.

In another study, samples of effluents from cotrimoxazole and piriton production of two pharmaceutical industries induced various types of chromosomal aberrations in *A. cepa* (Figure 11) and reduced the number of dividing cells by 38.6-67.2% at tested concentrations of 1-20% (Lateef *et al.,* 2007a). The effluents had microbial loads in the range of 1.85-3.5 × 10^7 cfu/ml, with the presence of *S. aureus*, *E. coli*, *Bacillus licheniformis, S. marcescens*, *Klebsiella* sp, *S. pyogenes*, *P. vulgaris*, *Yersinia* sp and *Bacillus subtilis*. The studies showed that exposure of fresh water to industrial wastes can adversely affect the quality of the water, thereby limiting the usefulness.

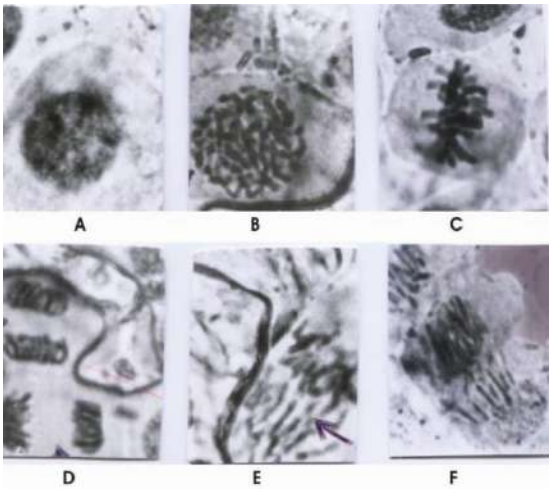


Figure 11: Photomicrographs of some normal stages (A-D) and aberrations (E & F) in mitotic division observed in the cells of *Allium cepa* treated with pharmaceutical effluents

In a related study (Adewoye and Lateef, 2004b), we examined the microbiological quality of fish (*Clarias gariepinus*) that were exposed to effluent of a detergent industry. It was discovered that exposure to the effluent increased the level of microbial contamination of the fish in all the parts that were examined, namely; skin, gills and muscle (Table 10). The bacterial load of fish surfaces ranged from 1.2-2.0 × 10^2 cfu/ml for the control, while values of 4.8-8.6 × 10^6 cfu/ml were obtained for the experimental fish exposed to the industrial effluent (0.025 ppm). The fungal count for the control ranged from 1.2 × 10^2-1.2 × 10^3 cfu/ml; while a range of 1.0-2.0 × 10^6 was obtained for the fish exposed to the industrial effluent.

Several microbes were isolated from the parts of the exposed fish samples as opposed to limited isolation in the control fish samples. The study concluded that exposure to the effluent might have predisposed the fish to broad bacterial and fungal infections that limited their quality for consumption because of extensive microbial contamination. The industry from where the effluent was collected discharges its wastewater into a nearby river. Other studies have shown the capability of a bacterium, *Bacillus safensis* LAU 13 for biosorption of heavy metals in the effluents of steel processing facilities (Ojoawo *et al.,* 2017), while health implications of hospital waste generation in Ogbomoso (Adeoye *et al.,* 2018) have been documented.

Mr. Vice-Chancellor, Sir, these studies underpinned the negative impact of industrial effluents in the environment from public health perspective and genotoxicology. Not only that these effluents stimulated the proliferation of several pathogenic organisms, they can also induce genetic damage in exposed organisms.

Table 10: Microbiology of *Clarias gariepinus*

*Fish part	Bacterial isolates	Fungal isolates
Skin		
Exposed	*Bacillus* sp, *Pseudomonas* sp, *Micrococcus* sp, *S. marcescens*, *S. faecalis*, and *Enterobacter aerogenes*	*Saccharomyces cerevisiae*, *Fusarium oxysporum*, and *Aspergillus fumigatus*
Control	*Micrococcus* sp	*Aspergillus niger*
Gill		
Exposed	*Streptococcus* sp, *S. faecalis*, *E. aerogenes*, *P. vulgaris*, *Micrococcus* sp, *Bacillus* sp, *E. coli*, *Pseudomonas* sp, *Bacillus subtilis* and *S. aureus*	*S. cerevisiae*, *Saccharomyces* sp, *Rhodosporium* sp, *Fusarium oxysporum*, and *Aspergillus fumigatus*
Control	*Micrococcus* sp	*Saccharomyces cerevisiae*
Muscle		
Exposed	*Micrococcus* sp, *S. aureus*, *Streptococcus faecium*, *P. vulgaris* and *Bacillus* sp	*Rhodosporium* sp, *Candida* sp, *Alternaria* sp and *Fusarium oxysporum*
Control	*Micrococcus* sp	ND

*exposed, fish samples exposed to 0.025 ppm of the effluent; control, fish samples not exposed to the effluent; ND, not detected

4.4 Microbiology of Drinks, Foods and Feeds

We have also carried out studies on orange juice products, *Akara Ogbomoso*, *Lafun* and poultry feeds with the view of determining their microbiological safety. In a study focusing on the microbiological assessment of sachet orange juice products, we analyzed forty samples of different brands with the incidence of bacteria (3.5×10^4-2.15×10^5 cfu/ml) and yeasts (7.5×10^4-1.25×10^5 cfu/ml)

in all the samples (Lateef *et al.*, 2004a). The incidence of *E. coli, Micrococcus* sp, *Bacillus subtilis, Streptococcus, pyogenes, Bacillus cereus, Staphylococcus aureus, Saccharomyces* sp, *Saccharomyces cerevisiae* and *Rhodotorula* sp in the orange juice samples was considered a safety concern as many of the organisms are pathogens.

In investigating the first study on the microbiology of the popular snack, *Akara Ogbomoso* (Figure 12), we recorded ample growth of aerobes, coliforms, staphylococci, *Shigella* and yeast/mold from the *Akara* samples, water and cowpea pastes (Table 11), which were indicative of poor processing techniques. To remedy the situation, we established Hazard Analysis and Critical Control Points (HACCP) plan for its production (Table 12). *Akara* prepared in the laboratory through the implementation of HACCP was not contaminated and found to be microbiologically safe (Lateef *et al.*, 2010a). The work stressed the relevance of application of HACCP to ensure safety of indigenous foods.

Figure 12: Samples of *Akara Ogbomoso*

Table 11: The average microbial loads of *akara* samples obtained from the production points

	Production points				
Microbial load ($\times 10^4$ cfu/g)	**A**	**B**	**C**	**D**	**E**
APC	$40.711^{(10)}$	$11.454^{(10)}$	$9.258^{(10)}$	$113.44^{(10)}$	$15.25^{(10)}$
CC	$25^{(2)}$	$0.07^{(2)}$	$0.089^{(10)}$	$0.902^{(10)}$	-
SSC	-	-	-	$0.005^{(1)}$	$0.02^{(1)}$
STC	$0.24^{(6)}$	$1.524^{(10)}$	$0.304^{(10)}$	$0.005^{(2)}$	$0.37^{(6)}$
MYC	$3.29^{(10)}$	$3.91^{(6)}$	$49.566^{(10)}$	$4.41^{(4)}$	$2.51^{(6)}$

APC, aerobic plate count; CC, coliform count; SSC, *Salmonella-Shigella* count; STC, staphylococcal count; MYC, mould-yeast count; *, microbial load is an average ten readings and has uniform index of 10^4; number in parenthesis indicate the number of positive samples

We have also evaluated the microbiological and nutritional qualities of poultry feeds in Ogbomoso, Southwest Nigeria, and determined the incidence of aflatoxins in the samples (Lateef and Gueguim-Kana, 2014). Over a course of five months, one hundred and fifty samples of different types of poultry feeds were obtained from five feed mills with high incidence of bacteria and fungi (Table 13). Further quality assessment showed that 36% of the feed samples were contaminated with aflatoxins. To improve the quality of the locally-produced poultry feeds, we evolved an effective HACCP plan. Efficient regulations for the production of feeds were recommended.

Table 12: Processing steps, sources of hazard and control measures in the production of *Akara* Ogbomoso

Processing steps	Sources of hazard	Hazard	Control measures
Procurement of beans/sorting	Beans	Chemicals and stones	Use of high quality beans
Soaking	Water, container, soil and sewage	Pathogens, and metals	Use of potable water
Removal of seed coat	Hands	Pathogens	Personal hygiene
Grinding	Milling machine	Heavy metals, pathogens	Personal hygiene/GMP
Moulding of cakes	Hand	Pathogens	Use of moulds, personal hygiene/GMP
Cooling	Air and baskets	Vegetative pathogens and spores	Cooling under basket covered with muslin cloth; regular cleaning of baskets
Packaging	Hand (picking), and mouth (air-blowing to open nylon)	Pathogens	Use forceps or wearing of gloves; good personal hygiene
Storage	Vegetative cells and spores	Pathogens	GMP, storage in freezing bags at low temperature; microwave heated for 10 seconds to be ready for consumption
Hawking/selling	Hand (through repackaging) and air	Pathogens and particulates	Personal Hygiene; discouragement of repackaging

Table 13: The microbiology of layer/starter feed

Samples	MC*	MAB*	Bacterial isolates
A	5.5	1.94	*S. aureus* (100), *B. cereus* (100), *P. aeruginosa* (100), *E. coli* (100) *S. marcescens* (20), *E. aerogenes* (20).
B	6.5	1.13	*E. coli* (100), *B. subtilis* (100), *P. aeruginosa* (100), *P. vulgaris* (20), *Micrococcus* sp (20).
C	5.8	0.50	*E. coli* (20), *Micrococcus* sp (40), *B. subtilis* (100), *P. aeruginosa* (100), *P. vulgaris* (100).
D	4.3	4.10	*S. aureus* (100), *B. cereus* (100), *P. aeruginosa* (100), *E. coli* (100), *S. marcescens* (20), *E. aerogenes* (20).
E	4.5	3.4	*S. aureus* (100), *B. cereus* (100), *P. aeruginosa* (100), *E. coli* (100), *P. vulgaris* (20), *B. subtilis* (100), *E. aerogenes* (20).

*, × 10^4 cfu/g; MC, mold count; MAB, mesophilic aerobe bacteria count; numbers in parenthesis are the frequency of isolation; values are average of ten measurements

More recently, Lateef and Ojo (2016) in a detailed investigation analyzed eight hundred samples of water, fermenting broth (24, 48 and 72 h) and final products in the processing of cassava tubers to produce *lafun* over a period of five months. All the dried *lafun* samples obtained from sixteen processors were contaminated with the cumulative microbial loads of 2.21-9.91 × 10^4 cfu/g and isolation of *S. aureus*, *E. coli*, *Salmonella* Typhimurium, *Lactobacillus* sp. *Bacillus cereus, Klebsiella oxytoca, Aspergillus fumigatus, A. flavus, A. niger, Absidia corymbifera* and *Rhizopus oryzae*. Aside, about 39 % of the fungal isolates produced aflatoxins ranging from 1 to 1600 µg/kg. The critical control points identified in the production were steeping,

drying, packaging/storage, and the implementation of the corrective measures led to the production of laboratory-prepared *lafun* with improved microbiological safety.

4.5 Antibiotic Resistance Studies

A major issue confronting public health all over the world is the emergence and spread of antibiotic or drug resistance mechanisms among microbes. The declining effectiveness of antibiotics on microbes imposes dire health and economic burdens on the society (Gandra *et al.*, 2014; Woolhouse *et al.*, 2016). Several mechanisms involved in antibiotic resistance have been unraveled and these include intrinsic factors such as membrane-bound action, efflux pump and resistance genes and their transfer (Cox and Wright, 2013) as well as extrinsic factors like abuse and wide-spread use of antibiotics in humans and animals, mis-diagnosis, wrong prescription, self-medication and non-compliance with treatment regimens (Davison *et al.*, 2000; Economou and Gousia, 2015; Ayukekbong *et al.*, 2017; Rather *et al.*, 2017).

Quite a lot of our researches have studies on antibiotic resistance phenomenon incorporated in them, with the view of determining the public health implications (Lateef and Oloke, 2003b; Adewoye and Lateef, 2004a; Lateef, 2004; Lateef *et al*., 2004a; Lateef *et al*., 2005; Lateef *et al*., 2006; Lateef *et al*., 2007a; Lateef *et al*., 2010a; Lateef *et al*., 2012a; Lateef and Gueguim-Kana 2014; Lateef and Ojo, 2016). In these works, several bacterial isolates were obtained from diverse environments, namely; foods, feeds, water, clinical, industrial effluent, and soil. The isolates were evaluated for their resistance to commonly used antibiotics (Table 14). These studies concluded that there is widespread multi drug-resistance phenomena among

bacterial isolates obtained from different samples in Southwest Nigeria (Lateef *et al.*, 2005; Lateef *et al.*, 2010a; Lateef and Ojo, 2016).

Table 14: Resistance patterns of some bacterial isolates obtained from *Akara Ogbomoso.*

No of antibiotics	Resistance patterns	Isolates
1	Cxc Flx	*S. epidermidis* *S. aureus*
2	Cxc Flx Cro Gen	*S. epidermidis* *Shigella* sp
3	Aug Cro Tet Aug Cro Amx Aug Cro Cot	*S. marcescens* *S. marcescens* *S. aureus*
4	Tet Amx Aug Cro Nit Aug Cot Cro Cot Cld Cxc Flx	*E. coli* *E. coli* *P. vulgaris*
5	Cpx Cot Cld Cxc Flx Aug Cro Cot Amx Nit	*B. cereus; S. aureus* *S. marcescens*
6	Aug Cro Cot Amx Nit Tet Aug Cro Cot Nit Tet Pfx	*E. coli* *E. coli*
7	Cip Gen Cpx Cot Cld Cxc Flx Aug Cro Cot Amx Nit Tet Pfx	*S. aureus* *E. coli*
8	Aug Ery Gen Cpx Cot Cld Cxc Flx Aug Cro Nit Gen Cot Ofl Amx Tet	*S. epidermidis* *C. freundii*
9	Aug Ofl Ery Gen Cpx Cot Cld Cxc Flx Aug Ery Cip Gen Cpx Cot Cld Cxc Flx	*S. aureus* *S. epidermidis*

Also, several bacterial strains produced β-lactamase, an enzyme noted for the detoxification of penicillins (Lateef, 2004; Lateef *et al.*, 2004a). The studies also identified some of the practices that may encourage

selection, enhancement and widespread of drug-resistance among bacteria and how to combat them. We have also carried out studies on the inhibitory effects of some disinfectants and antiseptics on resistant bacteria (Lateef and Oloke, 2005). The study demonstrated that disinfectants investigated were efficient; despite the resistance of the test organisms to antibiotics. It was inferred that the health of individuals could be safeguarded using the disinfectants.

4.6 Fabrication of Bioreactors, Control and Optimization of Fermentation Processes

Fermentation is the hallmark of industrial microbiology and biotechnology as several products can be produced by microorganism on a large scale via fermentation; which is concerned with biotransformation of substrates to high-end products. The fermentation process, which is of two types; submerged (SmF) and solid substrate/state (SSF) is conducted in specialized facilities called bioreactors (Figure 13). The bioreactor provides optimal conditions such as pH, aeration, temperature, agitation, and dissolved oxygen for the growth of microorganisms and product formation which must be properly controlled (Rolf and Lim, 1982; Rani and Rao, 1999).

Our research group ably led by Professor J.K. Oloke has carried out a lot of studies in this area; ranging from construction of bioreactors (Gueguim-Kana *et al*., 2003a; Gueguim-Kana *et al*., 2003b; Gueguim-Kana *et al*., 2010a; Gueguim-Kana *et al.,* 2005), through development of bioprocess software, Biopro_optimizer (Gueguim-Kana *et al*., 2003c; Gueguim-Kana *et al*., 2003d; Gueguim-Kana *et al*., 2010b) for acidification process of yoghurt

fermentation (Gueguim-Kana *et al*., 2007a), fermentation of yeasts using novel feeding strategy (Gueguim-Kana *et al*., 2007b), optimization of biogas and biohydrogen production (Gueguim-Kana *et al*., 2012a; Sewsynker *et al*., 2015), optimization of citric acid production (Gueguim-Kana *et al*., 2012c; Adeoye *et al*., 2015), enzyme production (Lateef and Gueguim-Kana, 2012; Lateef *et al*., 2012b; Elegbede and Lateef, 2019b) and exopolysaccharide production in mushroom (Adeeyo *et al*., 2016; Bamigboye *et al*., 2019). Figure 14 shows the generation of bioreactors produced by our team, while some software interfaces are shown in Figure 15.

Genetic algorithm software developed in-house has been used in these processes with commercial software on neural network to capture the non-linear relationship fermentation processes with outstanding outcomes, which are summarized in Table 15.

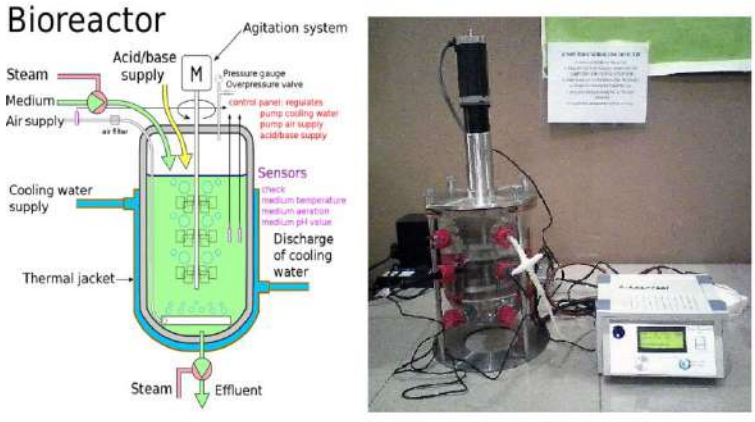


Figure 13: Basic diagram of bioreactor (A) and a functional 5-litre bioreactor in my laboratory

Figure 14: Generation of bioreactors produced by our team

Figure 15: Control panels of Biopro_optimizer

These studies demonstrated the ability to control fermentation process in a flexible and friendly environment (Gueguim-Kana *et al.*, 2007c) locally, as opposed to rigid conditions in imported bioreactors. It was also shown that local materials can be harnessed for the production of

bioreactors which can be easily controlled and attended to whenever there is need for servicing.

Table 15: The impact of optimization on some investigated bioprocesses

Bioprocess	Result	Reference
Yoghurt production by *Lactobacillus bulgaricus* and *Streptococcus thermophilus*	Novel temperature profile reduced fermentation time from 6 h to 2 h	Gueguim-Kana *et al.* (2007a)
Biomass of *Saccharomyces cerevisiae*	Novel feeding strategy increased biomass yield from 03 g/l to 14.25 g/l in 24 h	Gueguim-Kana *et al.* (2007b)
Biogas	Increase production of biogas by 8.64%	Gueguim-Kana *et al*. (2012a)
Biohydrogen	Analysis of 15 published showed that ANN can be used for modeling of biohydrogen production	Sewsynker *et al*. (2015)
Citric acid by *Aspergillus niger* MCBN 297	GA-ANN predicted citric acid yield better than RSM	Gueguim-Kana *et al*. (2012b)
Citric acid by *Aspergillus niger* FUO I_{10}	Improved citric acid yield by 45.97 folds	Adeoye *et al.* (2016)
Fructosyltransferase production by *Aspergillus niger*	Improved enzyme yield by 1-64-8.59 folds	Lateef *et al.* (2012b)
Fructosyltransferase production by *R. stolonifer* LAU 07	Improved enzyme yield by 3.80 folds	Lateef and Gueguim-Kana (2012)
Xylanase production by *A. niger* L3 and *Trichoderma longibrachiatum* L2	Improved enzyme yield by 192.59-208.09%	Elegbede and Lateef (2019b)
EPS production by *Lentinus edodes*	Improved yield by 20.70 folds	Adeeyo *et al.* (2016)
EPS production by *Pleurotus tuber-regium*	ANN modeled biomass and EPS production	Bamigboye *et al.* (2019)

GA, genetic algorithm; ANN, artificial neural network; RSM, response surface methodology; EPS, exopolysaccharide

4.7 Production of Fructooligosaccharides

Oligosaccharides are intermediate sugars between disaccharides and polysaccharides and usually have 3-10 sugar moieties connected by glycosidic bonds (Cummings and Stephen, 2007) (Figure 16). Oligosaccharides are either (a) malto-oligosaccharides (α-glucans), principally occurring from the hydrolysis of starch and (b) non-α-glucan such as raffinose and stachyose (α-galactosides), fructo- and galacto-oligosaccharides and other oligosaccharides. Most oligosaccharides are non-digestible. They can be obtained by direct extraction from natural sources (Figure 17), or produced by chemical processes hydrolyzing polysaccharides, or by enzymatic and chemical synthesis from disaccharides.

Oligosaccharides possess important physicochemical and physiological properties, and are claimed to behave as dietary fibers and prebiotics that support the growth beneficial microbes (Mussatto and Mancilha, 2007). As a result, oligosaccharides have been incorporated in to foods and drinks to produce functional foods. It has been projected that the probiotic market would reach $8.5 billion by 2024 (Fonteles and Rodrigues, 2018).

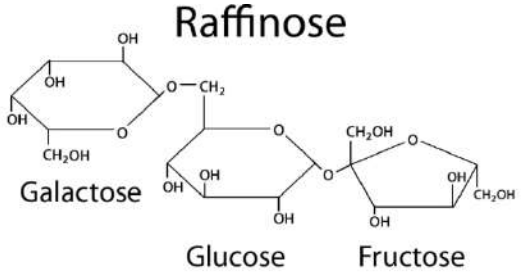


Figure 16: An example of oligosaccharide, raffinose

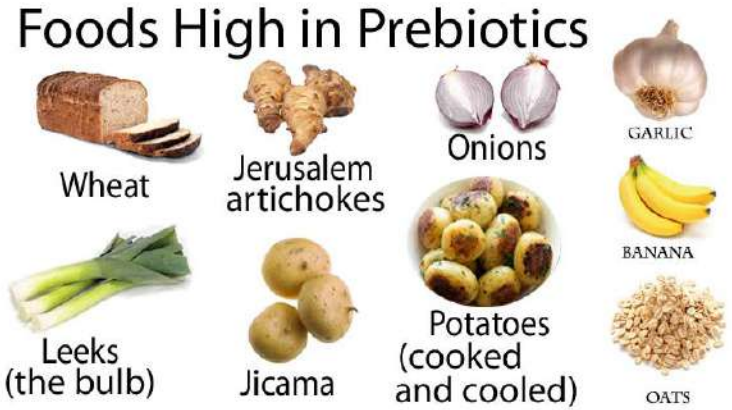


Figure 17: Some foods that are rich in prebiotics

Amongst oligosaccharides, fructooligosaccharides (FOS) also called oligofructose or oligofructan (Figure 18) have been investigated for their physiological and rheological attributes, as well as their sweetness (~60% as sweet as sucrose), thereby making them useful in food applications to reduce glycemic index and diabetes. Their health benefits (Khanvilkar and Arya, 2015) are as summarized in Table 16. Although, FOS are present in plants such as onions, chicory, garlic, asparagus, wheat, banana, artichoke, tomatoes and other fruits, vegetables and grains where they occur in small amounts (0.15-0.75%), they are currently produced on large scale using enzymatic fructosylation of sucrose by fructosyltransferase (FTase) (Vaňková *et al.*, 2008). FTases obtained from microorganisms have been used to produce FOS with very high yield in excess of 60% and up to 98% (Sangeetha *et al.*, 2015). Among the organisms that have been used industrially to produce FTase and FOS is the dimorphic black yeast, *Aureobasidium pullulans* (Yun, 1996).

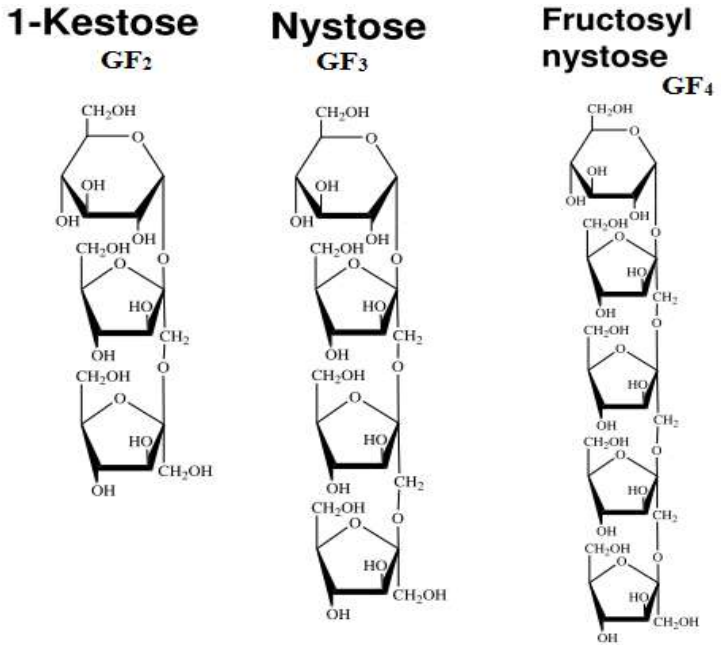


Figure 18: Structures of some fructooligosaccharides

Table 16: Some health benefits of fructooligosaccharides

S/N	Benefits	Purpose
1.	Promote growth of colonic beneficial microbes	Supportive colon therapy, fight against pathogens
2.	Enhance mineral absorption e.g. calcium	Improves bone formation and prevent osteoporosis
3.	Lower cholesterol, triglycerides	Fight against obesity and cardiovascular diseases
4.	Lower glucose level	Control/prevention of diabetes
5.	Reduce calorie intake	Weight management in obese
6.	Sweet (60% as sweet as sucrose)	As sweetener in drinks/foods
7.	Lead to formation of lactate, acetate and butyrate	Anticancer activity by apoptosis

Mr. Vice-Chancellor, Sir, my journey in to the world of oligosaccharides started during my PhD research by providence, because I actually wanted to work on microbial degradation of pesticides for my PhD. However, my supervisor, Prof. J.K. persuaded me to work on oligosaccharides having read the work of Dr. Prapulla (Prapulla *et al.,* 2000) which I photocopied at IITA library, Ibadan. I later worked in the laboratory of Dr. S.G. Prapulla in 2004-2005.

I have conducted several studies in this area (Lateef and Araromi, 2003; Lateef and Oloke, 2003a; Lateef *et al*., 2003b; Lateef *et al.*, 2004b; Lateef, 2005a,b; Lateef *et al*., 2007a,b; Lateef *et al*., 2008a; Lateef *et al*., 2012b; Ganaie *et al.,* 2014). In one of the studies, we examined the ability of a dimorphic fungus, *Aureobasidium pullulans* CFR 77 to produce FTase (Figure 19). It was established that application of ultrasound could be used to release intracellular FTase from the organism (Lateef *et al.*, 2007a). Ultrasonication at acoustic power of 20W for 9 minutes was found to be optimum to efficiently release intracellular FTase, which produced FOS yield of 57-59% within a reaction time of 9 h as against reaction times of 12-25 h reported in the literature. The study, which was first of its kind, demonstrated the potential role of ultrasonication in efficient release of the intracellular FTase which can be used for the production of FOS, an industrially important prebiotic.

We carried out purification and partial characterization of intracellular FTase of *Aureobasidium pullulans*. The FTase obtained by wet-milling of the organism was purified, with molecular weights of two bands of 147 and 170 KD, having optimum pH and temperature of 5.0 and 55 ^{o}C respectively (Lateef *et al.,* 2007b). In another study

(Lateef *et al*., 2008a), we reported the first reference to *Rhizopus stolonifer* LAU 07 as a producer of FTase. The local strain, which was isolated from spoilt orange fruit, produced FTase in submerged fermentation, which yielded 34% FOS.

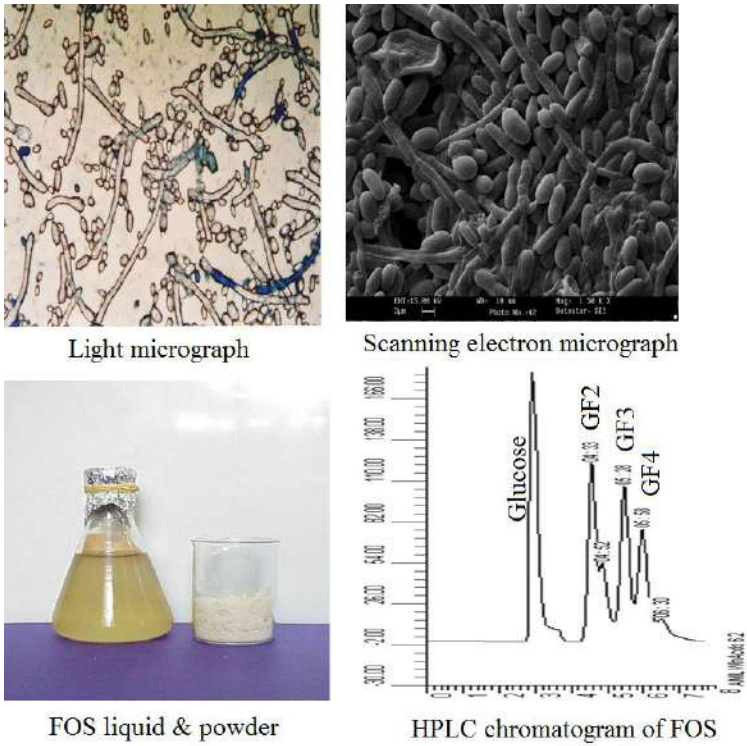


Figure 19: *Aureobasidium pullulans* CFR 77 for the production of FOS (Lateef *et al.*, 2007a, b)

Lateef *et al*. (2012b) reported a strain of *Aspergillus niger* which produced extracellular FTase in both submerged fermentation (SmF) in chemically-defined medium, and solid state fermentation (SSF) using

agricultural by-products such as kolanut pod and ripe plantain peel. Maximum enzyme activity of 24.49 U/ml was obtained in SmF after 48 h of fermentation, while maximum enzyme activities of 20.77 and 27.77 U/g were obtained in SSF using ripe plantain peel and kolanut pod, respectively. The enzyme was used to prepare FOS, with the maximum yield of 33.24%, consisting of kestose (GF2) and nystose (GF3). The safety of prepared FOS was investigated using albino rats. The study concluded that the prepared FOS may be considered safe for consumption as alternative sweetener to sucrose, as it did not produce any pathological effect in rats. In partnership with some internal collaborators, we also documented an excellent review on the current trends in the microbial production of FOS (Ganaie *et al.*, 2014). Some milestones on our contributions to FOS research are as summarized in Table 17.

Table 17: Milestones on contributions to FOS research

S/N	Scope	Reference
1.	First report of ultrasonication to release intracellular FTase	Lateef *et al.* (2007a)
2.	Reduction in reaction time to produce FOS from 12-25 h reported in literature to 9 h	Lateef *et al.* (2007a)
3.	First report of *Rhizopus stolonifer* to produce FTase and FOS	Lateef *et al.* (2008a)
4.	First report of kolanut pod and plantain peel as substrates to produce FTase in SSF	Lateef *et al.* (2012b)
5.	First report of use of cassava steep liquor and cassava peel as substrates to produce FTase and FOS in SmF & SSF	Lateef and Gueguim-Kana (2012)
6.	Excellent review of FOS production	Ganaie *et al.* (2014)

4.8 Utilization of Agro-industrial Wastes and Microbial Upgrading

Agro-industrial wastes which are abundant all over the world are known to be rich in nutrients that can support microbial growth on one hand, or can be used to produce some important microbial metabolites on the other hand; thereby leading to the microbial upgrading of the fermented substrates (nutrient enhancement) and biotechnological utilization, respectively (Ezejiofor *et al*., 2014*;* Jahan *et al.*, 2017). In this connection, we have conducted some studies on the biotechnological utilization of agro-industrial wastes such as whey, cocoa pod husk, palm kernel cake, kolanut pod, cassava peels, cassava wastewater, poultry feather, corn cob and sawdust (Lateef and Araromi, 2002; Araromi and Lateef, 2005; Lateef *et al*., 2010b; Lateef *et al*., 2012b; Gueguim-Kana *et al*., 2012a; Lateef and Gueguim-Kana, 2012; Adeoye *et al.,* 2015; Lateef *et al.,* 2015a; Elegbede and Lateef, 2018) for the production of glycol, xanthan gum, biogas, citric acid and enzymes such as FTase, xylanase and keratinase. We have also published excellent reviews on valorization of poultry feather waste to produce keratinase for diverse biotechnological applications (Adelere and Lateef, 2016a; Adelere and Lateef, 2019).

In the fungal fermentation by *Rhizopus stolonifer* LAU 07, the protein contents of substrates (cocoa pod husk, palm kernel cake, cassava peels) increased tremendously, while crude fibre contents were lowered. The cyanide content of cassava peel was lowered by 90.6%, while the antioxidant activity was improved by 53-62% among the fermented substrates (Lateef *et al.,* 2008b). The study showed that scope exists for microbial upgrading of these low-quality agro-wastes for the development of healthy animal feed supplements. We have also reported a strain of *Bacillus*

cereus LAU 08 which completely degraded whole chicken feather (Figure 20) within a period of seven days at room temperature (30 ± 2^{o}C) (Lateef *et al.,* 2010b). It produced keratinase as induced by hooves, horn and feather at growth temperature of 37 ^{o}C (Figure 21). Optimal keratinolytic activity was obtained at pH 7.0 and temperature of 50^{o}C; however more than 50% activities were displayed within the broad range of pH 7-9 and temperature of 40-70 ^{o}C. The isolate could be a promising strain for the management of chicken feather waste through novel biotechnological processes.

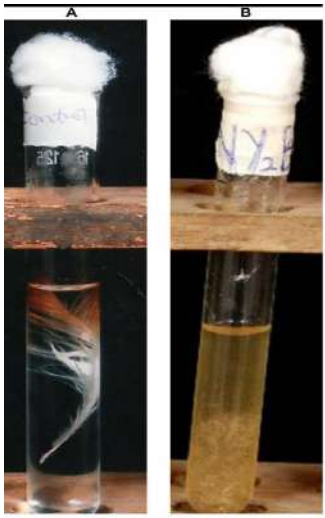


Figure 20: Biodegradation of feather (A, control; B, digestion after 7 days by *Bacillus cereus* LAU 08)

In 2013, through the research work of one of my excellent postgraduate students, we isolated a novel strain of *Bacillus safensis* LAU 13 (Lateef *et al.,* 2015a); the first report of the organism to produce keratinase with high titer of 108.5 U/ml. The keratinase produced by the bacterium

was investigated for dehairing and destaining activities with excellent performance (Figures 22 and 23).

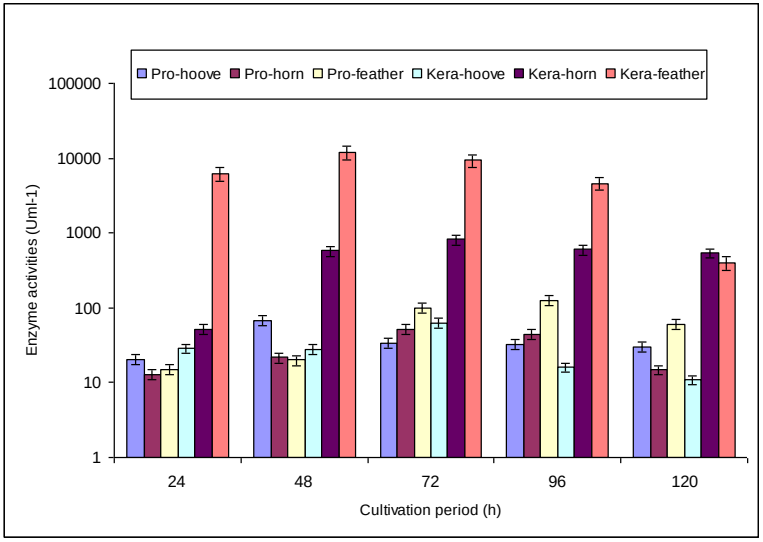


Figure 21: Keratinolytic (kera) and proteolytic (pro) activities of the crude extracellular keratinase of *B. cereus* LAU 08 grown on hooves, horn and feather

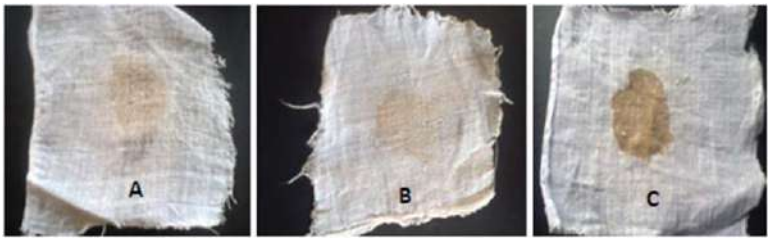


Figure 22: Destaining of blood-stained cloth by crude keratinases. Note: Destaining of blood by the wild-type strain after 3 h of incubation (A), by the mutant strain after 2 h of incubation (B) vs. a control (C) incubated in water

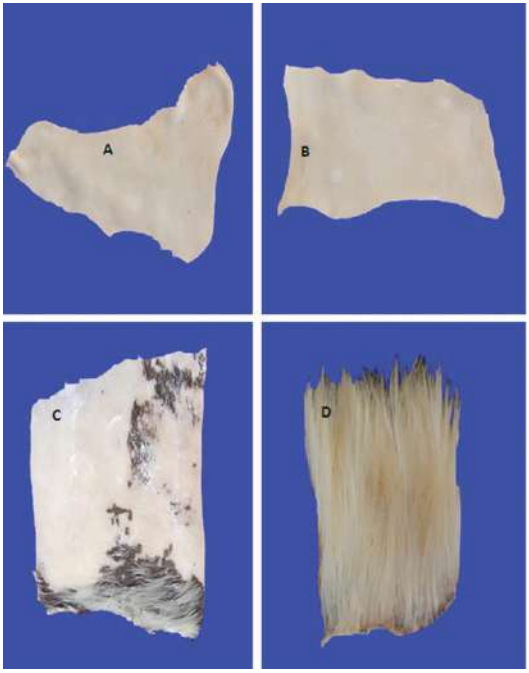


Figure 23: Complete dehairing of goat skin by crude keratinase. Note: Dehairing by wild-type strain after 16 h (A) and by mutant strain after 12 h (B); incomplete dehairing by sodium sulphide and lime after 20 h (C) and control (D)

Our contributions on *Bacillus safensis* which was first isolated as a contaminant in USA in 2006 (Satomi *et al.*, 2006) is legendary. We published its second report of isolation in Africa and the first report on its ability to degrade feather and produce keratinase (Lateef *et al.*, 2015a). Also, till date, the only review paper on the biology and biotechnological applications of the novel bacterium was authored by us (Lateef *et al.*, 2015b).

Furthermore, Elegbede and Lateef (2018) utilized corncob to produce xylanase by local strains of fungi in both SmF and SSF. High titers of xylanase in SmF (10.38-50.55 U/ml) and SSF (12.30-48.63 U/g) were produced by the fungi. The fungal isolates, namely *Aspergillus fumigatus* SD5A, *A. flavus* SD4A, *A. fumigatus* L1, *Fusarium solani* SD3C, *A. niger* L3, *Trichoderma longibrachiatum* L2, *Botryodiplodia* sp. L5 and *A. flavus* L4 did not produce aflatoxin (Figure 24) on neutral red desiccated coconut agar (Atanda *et al.*, 2011), thereby enhancing their biotechnological relevance in food industries. The fungal xylanases improved dough-rising (1.87-2.20 folds) in bakery application (Figure 25) and also clarified orange juice with good performance (58.12-74.22%).

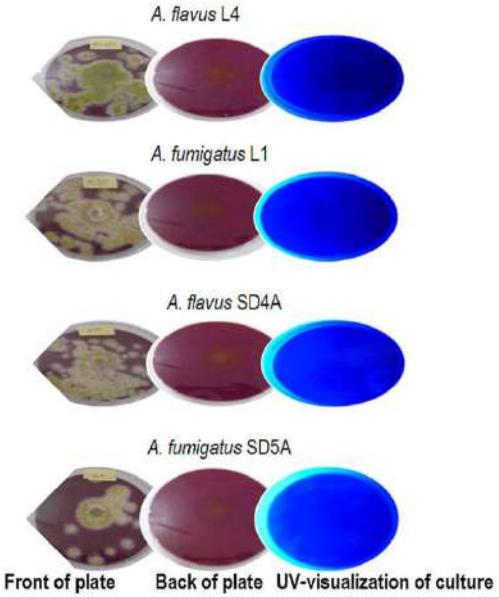


Figure 24: Non-aflatoxigenic nature of the fungal isolates

Mr. Vice-Chancellor, Sir, these studies have shown that agro-industrial wastes can be valorized for enhanced nutritional quality and to produce novel bio-products that can drive our quest for the diversification of the economy to incorporate bioeconomy.

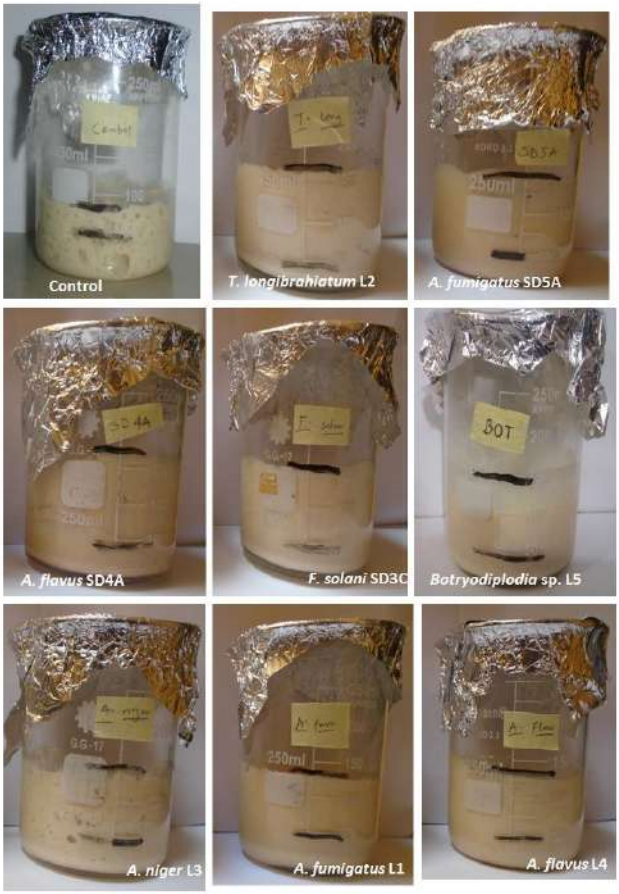


Figure 25: The effect of inclusion of xylanase on dough rising with good performance

4.9 Nanobiotechnological Research

4.9.1 Voyage into nanotechnology

Mr. Vice-Chancellor, Sir, my voyage into nanotechnology was accidental and borne out of genuine love from my friend of thirty years, Prof. M.A. Azeez, who while been on a postdoctoral fellowship and working on bio-inspired synthesis of nanoparticles in the Department of Chemistry, University of Pune, India in 2014 persuaded to have a shot at nanotechnology research. I considered his gesture very reluctantly; though as a long-term friend, we hardly dispute on issues, and even when we do, we always agree on a common ground. I therefore asked my postgraduate students to incorporate nanotechnology in their investigations. Within about 4 hours, I downloaded and assimilated about twenty papers, as I convinced myself that it was not something difficult for us to venture into.

I got the precursor (silver nitrate, $AgNO_3$) to synthesize the first silver nanoparticles (AgNPs) from the Department of Pure and Applied Chemistry, LAUTECH, Ogbomoso, and it was 'eureka', when Isiaka Adelere called to inform me that the colour of the reaction mixture had turned dark-brown upon addition of crude keratinase of *B. safensis* LAU 13 to $AgNO_3$ (Figure 26a). We contacted the Central University Research Laboratory to scan the UV-visible spectrum with maximum absorbance at 409 nm (Figure 26b) that falls within the range reported for AgNPs. The next stage was to obtain the micrograph of the particles; the morphology and size range to be determined. Luckily for us, after some few weeks of synthesizing the AgNPs, another worthy friend and research collaborator, Prof. E.B. Gueguim-Kana came visiting from South Africa, and we discussed at length about our research activities. When I told what we got at hand, he put up a call through

to South Africa, and he was told to bring along the sample of AgNPs for transmission electron microscopic imaging at the University of KwaZulu-Natal, South Africa. The study was the basis of my first paper on nanotechnology (Lateef *et al.*, 2015c). Since 2015, along with Dr. L.S. Beukes, we have published twenty-two articles together on nanotechnology. I have also published twenty-two papers with Prof. M.A. Azeez on nanotechnology.

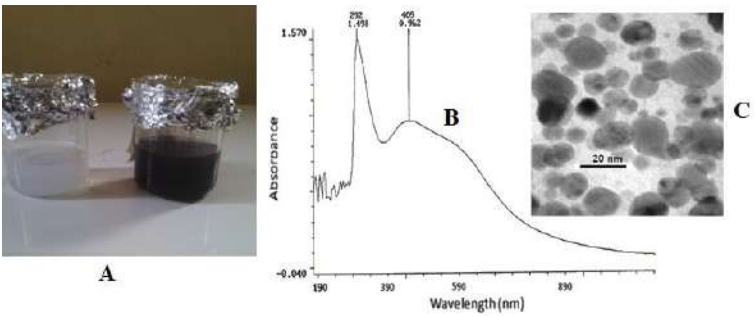


Figure 26: A, formation of AgNPs ($AgNO_3$ (left) AgNPs (right); B, UV-vis spectrum; C, TEM micrograph

4.9.2 Research on Silver Nanoparticles (AgNPs)

Mr. Vice-Chancellor, Sir, we have carried out several investigations into biofabrication of AgNPs using diverse biomolecules of plants, bacteria, fungi, and arthropods for antimicrobial, antibiotics-nanoparticles synergistic, dye-degrading and adsorption, desulphurization, corrosion inhibition, larvicidal, osmotic, anti-deterioration, heavy-metal remediating, plant-growth promoting, antioxidant, anti-inflammatory, anticoagulant and thrombolytic activities. These activities are relevant in biomedical, food, environmental, agricultural and industrial applications. Our activities in this area are as presented in Table 18.

Table 18: Summary of research activities on AgNPs

S/N	Biomaterial	Highlight	Reference
1.	Second report of keratinase	Antimicrobial	Lateef *et al.* (2015c)
2.	First report of seed and seed shell of *Cola nitida*	Antibacterial	Lateef *et al.* (2015d)
3.	First report of extract of *B. safensis*	Antimicrobial, antioxidant and larvicidal	Lateef *et al.* (2015e)
4.	Laccase of *L. edodes*	Antibacterial	Lateef and Adeeyo (2015)
5.	First report of cobweb	Antimicrobial, paint additive and antibiotic-AgNPs synergy	Lateef *et al.* (2016b)
6.	First report of pod of *Cola nitida*	Antibacterial, antioxidant and paint additive	Lateef *et al.* (2016c)
7.	First report of cocoa pod	Antimicrobial, antioxidant and larvicidal	Lateef *et al.* (2016d)
8.	First report of nest of paper wasp	Antimicrobial, catalytic, anti-coagulant and thrombolytic	Lateef *et al.* (2016e)
9.	First report of miracle fruit plant	Antimicrobial, catalytic, anti-coagulant and thrombolytic	Lateef *et al.* (2016f)
10.	Cell-free extract of *B. safensis*	Anti-candida, anti-coagulant and thrombolytic	Lateef *et al.* (2016g)
11.	First report of cocoa bean	Antimicrobial, larvicidal and anticoagulant	Azeez *et al.* (2017a)
12.	Cell-free extract of *Enterococcus* sp	Antimicrobial	Oladipo *et al.* (2017a)
13.	Cobweb and Kola nut pod	Desulphurization of model oil	Olajire *et al.* (2017)
14.	Cobweb and Kola nut pod, seed and seed shell	Hydrogen peroxide scavenging, anticoagulant and thrombolytic	Lateef *et al.* (2017)
15.	Pod of *Cola nitida*	Enhanced antioxidants and phytochemicals in *Amaranthus caudatus*	Azeez *et al.* (2017b)
16.	Kola nut pod, seed and seed shell	Cytogenotoxicity	Yekeen *et al.* (2017a)

S/N	Biomaterial	Highlight	Reference
17.	Cocoa pod and bean	Cytogenotoxicity	Yekeen *et al.* (2017b)
18.	First report of wonderful kola	Antimicrobial	Adelere *et al.* (2017)
19.	Cobweb	Adsorbent for Rhodamine B	Azeez *et al.* (2018)
20.	First report of xylanase	Catalytic and biomedical	Elegbede *et al.* (2018)
21.	First report of *Petiveria alliacea*	Biomedical	Lateef *et al.* (2018a)
22.	*Lentinus squarrosulus*	Antibacterial	Aina *et al.* (2018)
23.	Cocoa pod	Antiphytopathogenic and hepatoprotection	Azeez *et al.* (2019a)
24.	Cocoa bean	Osmotic dehydration of tomato	Azeez *et al.* (2019b)
25.	Cocoa pod	Remediation of Cd and Pb polluted soil	Azeez *et al.* (2019c)
26.	*Chasmanthera dependens*	Biomedical	Aina *et al.* (2019)
27.	First report of *Persea americana*	Antimicrobial and antioxidant	Adebayo *et al.* (2019a)
28.	First report of *Opuntia ficus-indica*	Antimicrobial and antioxidant	Adebayo *et al.* (2019b)
29.	Cocoa bean	Adsorption of Rhodamine B	Azeez *et al.* (2020a)
30.	*Hyptis suaveolens*	Biomedical	Lateef *et al.* (2020)
31.	First report of animal fur	Biomedical and cytogenotoxicity	Akintayo *et al.* (2020)
32.	*Carica papaya*	Antibacterial and Larvicidal	Aina *et al.* (2020)
33.	*Ehretia cymosa*	Anti-inflammatory	Adeleye *et al.* (2020)
34.	Kola nut pod	Corrosion inhibition	Asafa *et al.* (2020)
35.	Kola nut pod	Anti-aging of bitumen	Olabemiwo *et al.* (2020)
36.	*Annona muricata*	Biomedical	Badmus *et al.* (2020)
37.	Cobweb extract	Improved paint	Asafa *et al.* (2021)

Some of the fascinating results obtained in these studies are illustrated in Figures 27-34.

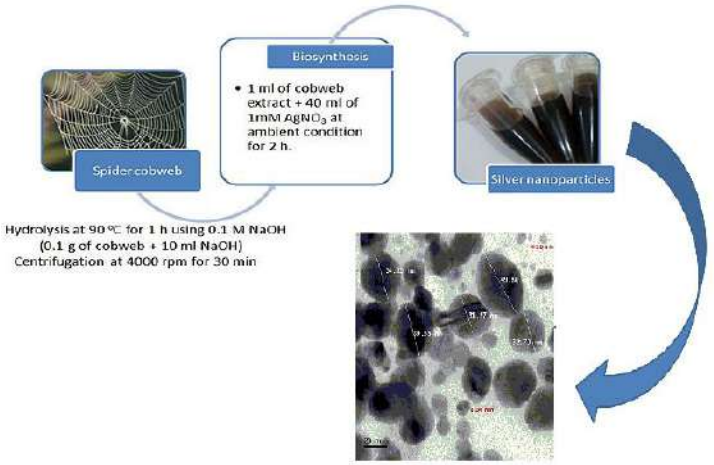


Figure 27: Scheme for the synthesis of AgNPs using cobweb extract

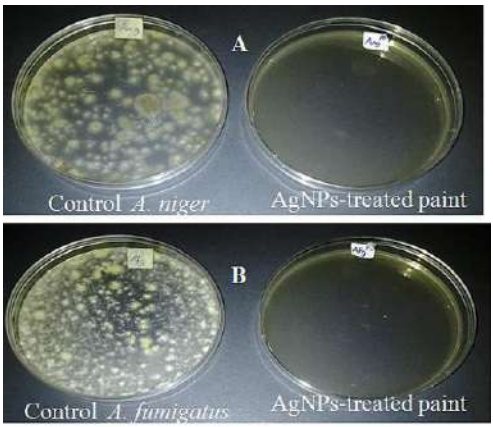


Figure 28: Antifungal effect of AgNPs when used as additive in emulsion paint

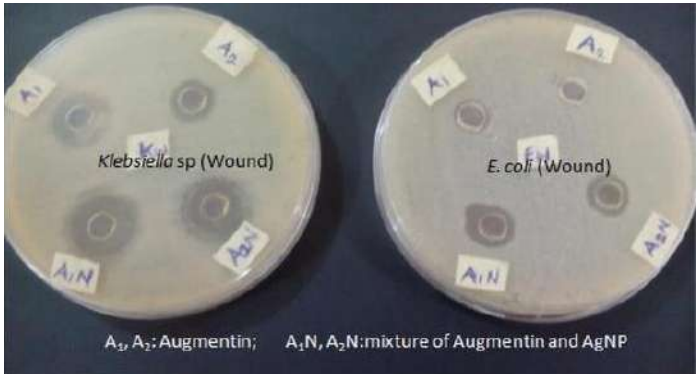


Figure 29: Synergistic effect of AgNPs on Augmentin (upper, antibiotic alone; lower, antibiotic-AgNPs) against drug-resistant bacteria

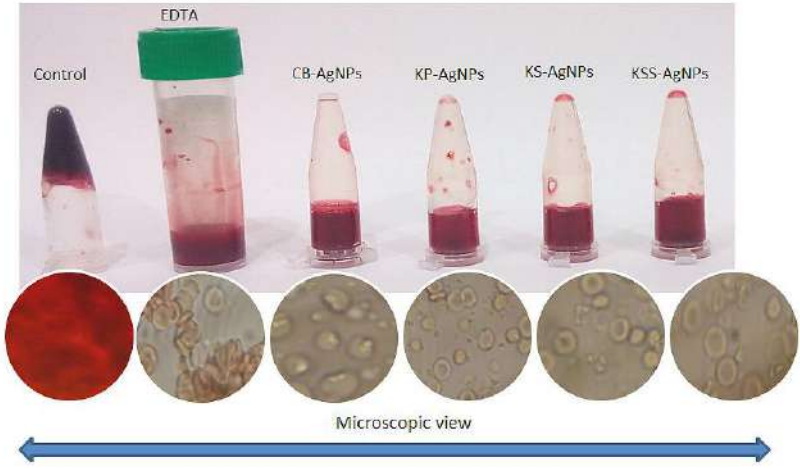


Figure 30: Anticoagulant activities of biosynthesized AgNPs on human blood

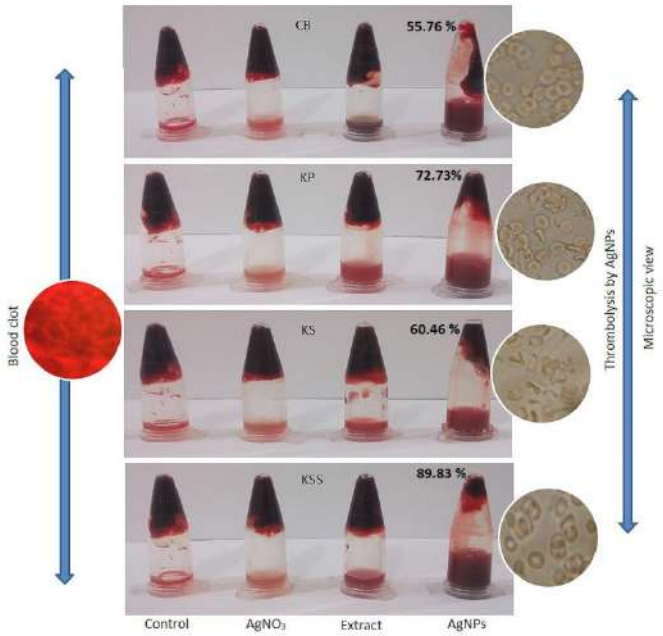


Figure 31: The thrombolytic activities of some biosynthesized AgNPs

Figure 32: The effect of biosynthesized AgNPs on amelioration of cadmium on the growth of *Moringa oleifera* (A, control; B, cadmium treated; C, amelioration with AgNPs)

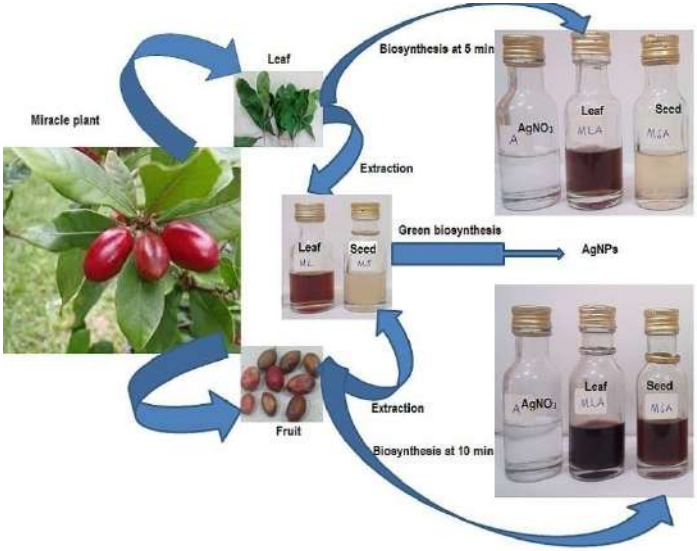


Figure 33: Biosynthesis of AgNPs using leaf and seed extract of *S. dulcificum*

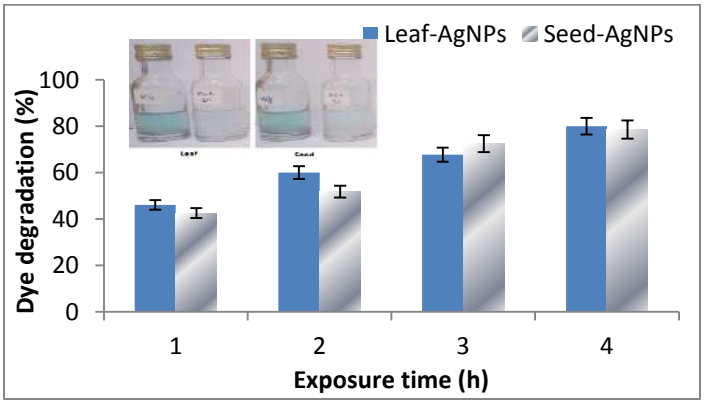


Figure 34: Degradation of malachite green by biosynthesized AgNPs using leaf and seed extracts of *S. dulcificum* (inset, degradation at 2 h).

4.9.2 Research Activities on Gold (AuNPs), Silver-Gold alloy (Ag-AuNPs), Calcium (CaNPs) and TiO_2 NPs

Unlike silver, bulk gold is not acknowledged to have inherent antimicrobial properties. However, the properties of gold at nanoscale allow for robust particle functionalization, and researchers have explored the prospect of using AuNPs as antimicrobial agent. Also, the simultaneous reduction of Ag and Au ions in the mixed solution has led to the development of bimetallic Ag-Au nanoparticles with higher activities as antimicrobials compared to AgNPs and AuNPs and also biocompatible for biomedical applications. Bimetallic nanoparticles have gained attentions in their synthesis and applications, owning to the fact that they combine attributes of the monometallic components by altering the molar ratios of the two metals. Unlike Ag and AuNPs however, the reports on biomedical applications of green Ag-AuNPs are scanty (Lateef *et al.*, 2019).

Calcium is a macronutrient essential to plants and animals for several physiological activities that include enzymatic activities, hormonal system signaling, antioxidant activity and bone development in vertebrates. The biofabrication of calcium nanoparticles has also be on a steady rise for different applications (Lin *et al.*, 2017; Lu *et al.*, 2017; Uskoković *et al.*, 2019; Levingstone *et al.* 2020).

We have carried out investigations on the biosynthesis and applications of AuNPs, Ag-AuNPs, CaNPs and TiO_2NPs in our laboratories for environmental, biomedical and agricultural applications over the years, which are summarized in Table 19 and some of the results presented in Figures 35-40.

Table 19: Summary of research activities on AuNPs, Ag-AuNPs, CaNPs and TiO_2 NPs

S/N	Biomaterial used	Nanoparticles	Highlight	Reference
1.	First report extract of *B. safensis*	AuNPs and Ag-AuNPs	Antifungal, dye degradation, anti-coagulant and thrombolytic	Ojo *et al.*(2016)
2.	First report of leaf, pod, seed and seed shell of Kola nut	Ag-AuNPs	Antifungal, catalytic, larvicidal and thrombolytic	Lateef *et al.* (2016h)
3.	First report of cell-free extract of *Enterococcus* sp	AuNPs	Antioxidant, larvicidal, anti-coagulant and thrombolytic	Oladipo *et al.* (2017b)
4.	First report of xylanase	Ag-AuNPs	Biomedical and catalytic	Elegbede *et al.* (2019)
5.	First report of *Persea americana*	AuNPs and Ag-AuNPs	Antimicrobial and antioxidant	Adebayo *et al.* (2019a)
6.	First report of *Opuntia ficus-indica*	AuNPs and Ag-AuNPs	Antimicrobial and antioxidant	Adebayo *et al.* (2019b)
7.	First report of xylanase	AuNPs	Biomedical	Elegbede *et al.* (2020)
8.	First report of *Datura stramonium* seed	AuNPs	Antidiabetic	Oladipo *et al.* (2020a)
9	*Datura stramonium* seed	AuNPs	Biomedical	Oladipo *et al.* (2020b)
10	First report of pod extract of *Cola nitida*	CaNPs	Enhanced plant growth and phytochemicals	Azeez *et al.* (2020c)
11	First report of kola nut extracts	TiO_2NPs	Biomedical and catalytic	Akinola *et al.* (2020)

Figure 35: Spectrum of colloidal AuNPs biofabricated by different species of *Enterococcus*

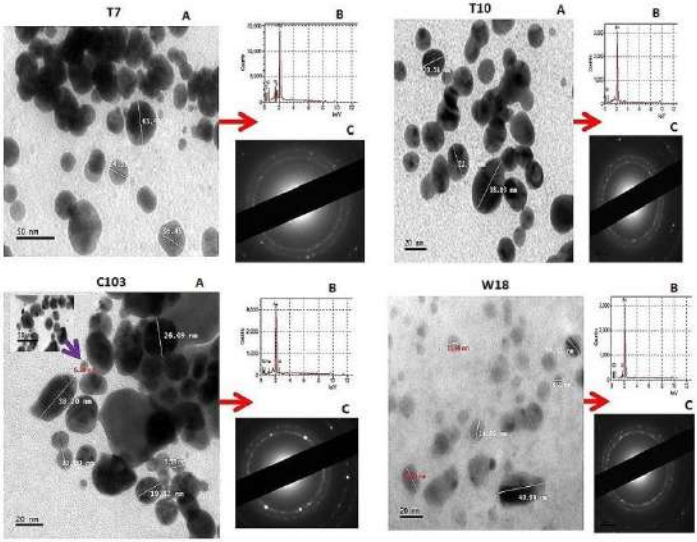


Figure 36: TEM, SAED and EDX of AuNPs biofabricated by different species of *Enterococcus*

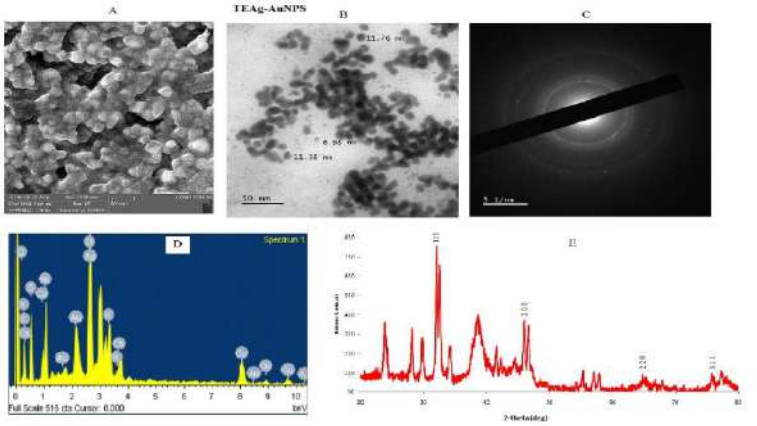


Figure 37: FESEM (A), TEM (B), SAED (C), EDX (D) and XRD (E) of biosynthesized Ag-AuNPs

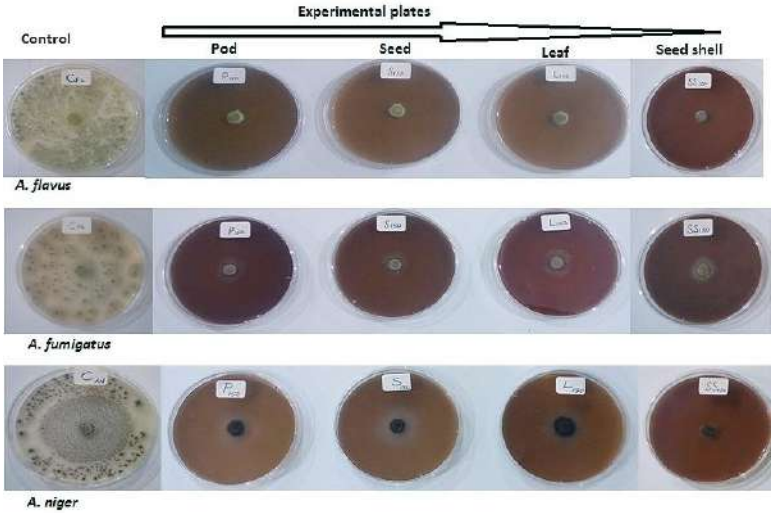


Figure 38: Antifungal activities of biosynthesized Ag-AuNPs using kolanut

4.9.3 Contributions of Review Articles

Mr. Vice-Chancellor, Sir, we have made enourmous contributions to topical issues on nanotechnology by publishing excellent reviews as summarized in Table 20.

Table 20: Review articles on nanotechnology

S/N	Focus	Highlight	Reference
1.	Use of agrowastes, enzymes and pigments to synthesize metal nanoparticles (MeNPs)	1st report to highlight the contributions of these biomaterials to nanotechnology	Adelere and Lateef (2016b)
2.	Use of arthropods and their metabolites to synthesize MeNPs	1st compendium on arthropods in nanotechnology	Lateef *et al.* (2016a)
3.	Applications of nanoparticles to manage blood coagulation disorders	Documented anticoagulant, thrombolytic and theranostic activities of nanoparticles	Lateef *et al.* (2018b)
4.	Green nanotechnology research in Nigeria	1st compendium on prospects and challenges of green nanotechnology research in Nigeria	Elegbede and Lateef (2019a)
5.	Biomedical applications of MeNPs	1st compendium on Ag, Au and Ag-AuNPs for biomedical applications	Elegbede and Lateef (2019c)
6.	Biomedical applications of green synthesized MeNPs	Elaborated on biomedical applications of several MeNPs	Lateef *et al.* (2019)
7.	Nanotechnology in the built environment	Applications of nanomaterials in built environment	Elegbede and Lateef (2020)
8.	Application of Ag and AuNPs as anticoagulant and thrombolytic agents	Highlights prospects of Ag and AuNPs in biomedical practice	Azeez *et al.* (2020b)
9	Nanobiosensors	Applications in biomedical technology	Banigo *et al.* (2020)

4.9.4 Bridging the Gap between Microbiology and Nanotechnology: The sub-discipline of Microbial Nanobiotechnology

Mr. Vice-Chancellor, I have lived up to my promise to situate nanotechnology in microbiology, and these efforts have come to fruition in producing the pioneering textbook in Microbial Nanobiotechnology. I rallied scientists in seven countries in Asia, Africa, South America and Europe to produce the exciting 588-page textbook, 'Microbial Nanobiotechnology: Principles and Applications' published by Springer-Nature in 2021 (Lateef *et al.*, 2021a). In this textbook, the contributions of microorganisms to developments in nanotechnology, in terms of microbial synthesis of nanoparticles, interactions and their applications in diverse areas were articulated in manners that will appeal to microbiologists and life scientists in general.

In chapter one of the textbook, I brought my experiences to bear in establishing the links between microbiology and nanotechnology (Figure 39), identify the gaps in knowledge and provided ways to address the challenges in the development of microbial nanobiotechnology, including a draft curriculum of an introductory course in nanobiotechnology (Lateef *et al.*, 2021b). My research team also contributed other chapters in the book on nanozymes (Elegbede and Lateef, 2021), algal nanobiotechnology (Adelere and Lateef, 2021), and beneficial microbes in the synthesis of nanoparticles and applications in nanomedicine (Adebayo *et al.*, 2021).

With the publication of this masterpiece, Mr. Vice-Chancellor and distinguished ladies and gentlemen, I am fulfilled as a microbiologist, biotechnologist and nanobiotechnologist.

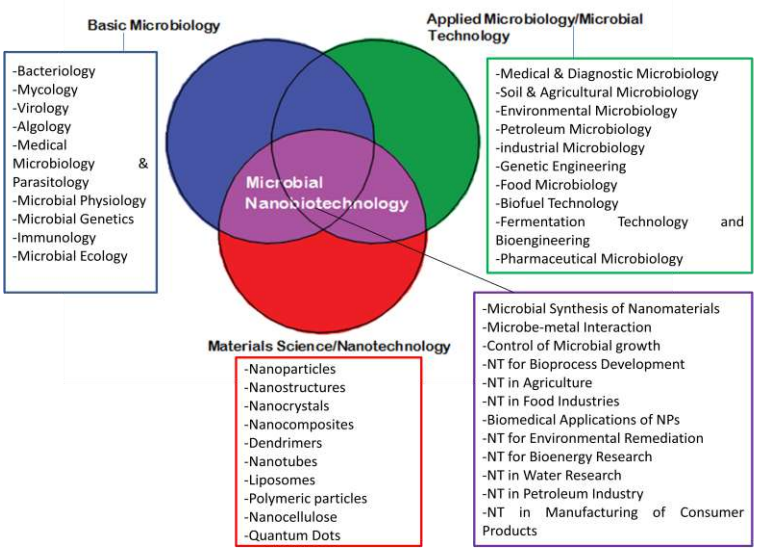


Figure 39: The interrelatedness of microbiology, microbial technology and nanotechnology for the creation of microbial nanobiotechnology

4.9.5 Activities of the LAUTECH Nanotechnology Research Group (*NANO*$^{+}$)

Mr. Vice-Chancellor, the LAUTECH Nanotechnology Research Group which is multidisciplinary was formed on September 4, 2014 with the main purpose of conducting cutting-edge research in nanotechnology, training of manpower and dissemination of information on nanotechnology. As of now, the group has eleven members from the faculties of Pure and Applied Sciences, Basic Medical Sciences, and Engineering and Technology of this University (Figure 40).

Figure 40: Members of the Research Group (Left, Prof. A. Lateef (PAB); top, Dr. I.C. Oladipo (SLT), Prof. T.A. Yekeen (PAB), Prof. M.O. Durowoju (Mech. Engr.), Dr. E.A. Adebayo (PAB), Dr. J.A. Badmus (Biochem); below, Prof. M.A. Azeez (PAB), Dr. T.B. Asafa (Mech. Engr.), Prof. Y.K. Sanusi (PAP), Dr. M.K. Awodele (PAP) and Dr. O. Adedokun (PAP)

The group has consistently positioned LAUTECH as a centre of reference in nanotechnology research in the last six years. The modest achievements of the group are as stated in Tables 21 and 22, while pictures depicting its activities are presented in Figures 41-44.

All these researches and engagements along with those of other excellent scholars in LAUTECH have positioned the University as a respected citadel of learning with good academic ranking. In a study reported in 2016 on the scientometrics of Google Scholar Citation, it was shown that LAUTECH scholars have contributed immensely to the generation of knowledge in Africa (Lateef *et al.*, 2006i).

Table 21: Achievements of *NANO*$^{+}$

S/N	Achievements
1.	Publication of more than one hundred articles on nanotechnology since 2015
2.	Aggressive web presence; www.lautechnanotech.com with record of more than 110,000 visitors since its debut on June 24, 2016
3.	Successful organization of workshop on nanotechnology in 2017 and workshop cum conference in 2018, 2019 and 2020
4.	Publication of a special issue of *Science Focus* **23** (2) dedicated to papers presented at LAUTECH NANO 2018 conference
5.	Publication of papers presented at LAUTECH NANO 2019 conference in Volume **805** of *IOP Conference Series: Materials Science and Engineering* (UK) in 2020
6.	Training of several undergraduate and postgraduate students. At least six M. Tech students have been trained, while several M. Tech and PhD students are under training
7.	Collaboration with researchers in South Africa, India, Saudi Arabia and Italy. At least a student has enjoined postgraduate fellowship with one of our partners
8.	Mentored several colleagues at LAUTECH, UNIOSUN, KWASU, BABCOCK, UNILORIN, OOU, UNILAG, UI, FUT MINNA, FOUNTAIN & FUTO
9.	Sensitization of younger generation in primary and secondary schools on nanotechnology discourse, including organization of essay competition
10.	Massive dissemination of information on nanotechnology in international and national online and print media
11.	Launching of the group's journal, '*Nano Plus: Science and Technology of Nanomaterials',* the first of its kind in the sub-Sahara Africa (https://stnanojournal.org/).

Table 22: Media outreach on the activities of *NANO*$^{+}$

S/N	Title	Reference
1.	Despite varsity closure, LAUTECH set to lead Nigeria in nanotechnology	City Mirror (2017)
2.	LAUTECH hosts workshop on nanotechnology-Restates call for proper funding of varsities	The Nigerian Tribune (2017)
3.	Nanotech holds promise for Africa, but not prioritized	SciDev.Net (2017)
4.	2nd LAUTECHNANO Conference Holds in October	National Insight (2018)
5.	Improved research funding critical to raising education standard – Researchers	The Guardian (2018a)
6.	Group calls for proper research funding in tertiary institutions	The Business Day (2018a)
7.	Science minister indicates govt support for nanotechnology at LAUTECH 2018	City Voice (2018)
8.	LAUTECH researchers underscore importance of Nanotechnology	The Nigerian Tribune (2018)
9.	Minister urges increased research in nanotechnology	The Guardian (2018b)
10.	Focus on product formation studies, science minister tells research institutes	The Business Day (2018b)
11.	Minister tasks researchers, institutes on product-centered studies	Daily Independent (2018)

Table 22 Cont'd

S/N	Title	Reference
12.	Scholars to appraise opportunities, constraints of nanotechnology	The Guardian (2019a)
13.	LAUTECH *NANO*$^{+}$ urges government to fund research into nanotechnology	The Business Day (2019a)
14.	Funding, power, political commitment obstacles to academic research in higher institution	The Business Day (2019b)
15.	LAUTECH demands centre of excellence in nanotechnology	The Nigerian Tribune (2019)
16.	LAUTECH VC wants special funding for nanotechnology research	The Nation (2019)
17.	FG urged to fast-track passage, implementation of national policy on nanotechnology	The Guardian (2019b)
18.	LAUTECH urges TETFund to prioritize funding nanotechnology research in Nigeria	The Business Day (2019c)
19.	FG urged to hasten policy on nanotechnology	The daily Trust (2019)
20.	Nigeria needs roadmap for nanotechnology policy, development	The Guardian (2020a)
21.	Onu assures of FG commitment to nanotechnology research, development in Nigeria. Says ministry will support establishment of nano centre at **LAUTECH**	The Nigerian Tribune (2020)
22.	Nanotechnology is a veritable tool to achieving SDGS, say scholars	The Guardian (2020b)

Figure 41: Faces at the workshop on synthesis, characterization and applications of nanoparticles held on 21-24 August, 2017

Figure 42: Participants at the workshop on synthesis, characterization and application of nanoparticles on 23 October, 2018

Figure 43: Group photograph of members of *NANO*$^{+}$ with guests at the opening ceremony of LAUTECH NANO 2018 on 24 October, 2018

Figure 44: Faces at the LAUTECH NANO 2019 Conference held on 22-24 October, 2019

4.9.6 Other Activities to Promote Nanobiotechnology Research

I have been engaged in series of activities to promote nanobiotechnology research within and outside Nigeria. This include infusion of nanobiotechnology into the curriculum of introductory biotechnology that is taught at 500 level in the Department of Pure and Applied Biology, LAUTECH, Ogbomoso which is not in existence in any University in Nigeria. This effort put our graduates at advantage with exposure to the cutting knowledge of nanotechnology. I have also extended the promotion of nanobiotechnology research through public lectures. In 2020, I delivered two public lectures via webinar in two colleges in India (Lateef, 2020a, b) to stimulate the interests of life scientists in nanotechnology.

5.0 The Intricate Cycle of Man, Microbes, Nanoparticles and Development: Personal Experience

Mr. Vice-Chancellor, Sir, from my research efforts, I have found several microbes and nanoparticles as tools to render goods and services for mankind, and to drive development agenda. In doing so however, we need to exercise caution; particularly in the areas of water and food safety, and pollution of the environment by domestic, agricultural and industrial wastes. The recent event of COVID-19 has shown for instance how microbes can threaten the very existence of mankind, whereby social, religious, economic, political, educational sectors and well-being of man were disrupted by a microbe, a novel coronavirus. The abuse in the use of antibiotics and dissemination of drug-resistant isolates also contribute to threats facing mankind, in terms of control and treatment of

diseases. As long as these precautions are not observed, microbes can portend serious danger to man, most especially practices that encourage creation, development and dissemination of resistant strains.

While nanoparticles that I have worked on have been shown to have potentials for applications in agriculture, healthcare, pollution control, food and water treatment; the very characteristics that enhance the performance of the particles can also enhance their toxicity in the other way round. Therefore, care should be taken in establishing the toxicological attributes of these particles to ascertain their safety on case by case basis and their subsequent applications.

Both microbes and nanoparticles belong to minute materials and objects that cannot be seen by man without magnifying equipment. Typically, their sizes range from 10^{-6} (1 millionth) to 10^{-9} (1 billionth) metre. They are very small, yet they have defined man in his activities in several ways as enunciated in this lecture. They contribute to the well-being of man, they dominate economic activities in the world, man has used them to produce products for his convenience, they have elevated the living conditions of man, and they put food on the table of man.

Conversely, microbes and nanoparticles as small as they are can also subject man to unimaginable distress; can cause diseases, can harm/kill man, his animals and cultivated crops, can cause economic crisis, can instill terror or fear in man, and they can simply put man on his knees, while he is helpless! Over ages, man has been assaulted by microbes especially, leading to the death of millions of people. Be it malaria, tuberculosis, polio, small pox, Ebola, Lassa fever, diarrhoea, COVID-19, cholera, tetanus, meningitis, syphilis, bubonic plagues, hepatitis,

HIV-AIDS, food poisoning (through mycotoxins), man has suffered in no small measure from microbes (Kilbourne, 2006; Brundage and Shanks, 2008; Dean *et al,* 2018; Chopra *et al.,* 2019; Fedson, 2019; Ashton, 2020).

Mr. Vice-Chancellor, Sir, is it not a paradox that both good things of this life and the bad ones are instigated by these diminutive living and non-living things? They are the foot soldiers of development and doom; it is left for man as a commander to responsibly deploy them for the common good and continuous existence of man; to walk the intricate cycle with utmost care. **So, the next big thing would be determined by small things……whether positively or negatively.**

It is on the shoulders of these small things that I stand and projected to the whole world as a scholar, contributing to the body of knowledge for the benefits of mankind. I came across microbes and nanoparticles at LAUTECH and I have used them to promote the image of LAUTECH through my research activities. At several research and development fairs in LAUTECH and at national level (organized by National Universities Commission), our activities have won laurels (Figures 45 and 46)**.** Today, LAUTECH is on the radar of nanotechnology research largely because of our little contributions in this area. **The next big things are going to be small really!** For Allah says 'I create other things you do not know (or have knowledge of) (Qur'an Chapter 16 Verse 8). Also, since He admonished man in Qur'an 96: 1-5 to read, seek knowledge and taught him what he knew not, I shall continue to seek knowledge about the world of the unknown for the good of man and in service to the creative creator of the universe.

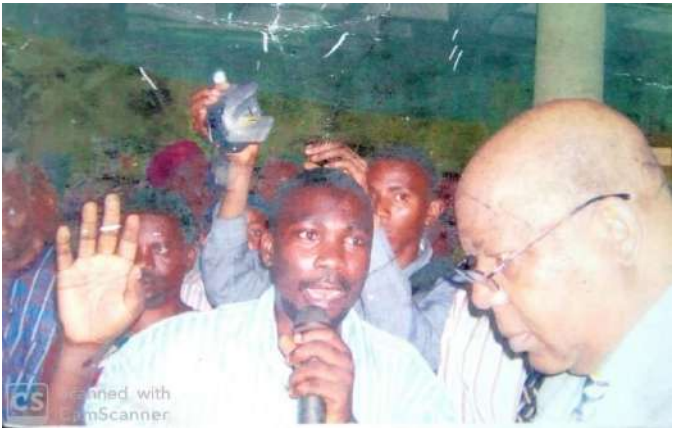


Figure 45: Then as Dr. A. Lateef explaining the research work on fructooligosaccharides to Prof. B.B. Adeleke (The then VC of LAUTECH) at the 2006 edition of LAUTECH R&D fair. The work won **2nd prize** among all research works at the fair

6.0 Conclusions and Recommendations

Mr. Vice-Chancellor, Sir, this lecture has shown us the importance of microbes and nanoparticles to man, to the extent that they can be exploited as tools for the much needed change to bring about sustainable development. This is the hallmark of my research activities in the last twenty-two years as an industrial microbiologist, biotechnologist and Nanobiotechnologist. In pursuance of this, I have trained several students and also mentored junior colleagues in several Universities as well as established a laboratory of reference for research in my areas of expertise, the Laboratory of Industrial Microbiology and Nanobiotechnology.

Figure 46: The 'Team LAUTECH' that represented the University with their research works at NUC Research and Development fair in Abuja in 2006, where LAUTECH was ranked **3rd** among all Universities in Nigeria and **1st** among the state Universities (1, Dr. Gueguim-Kana; 2, Prof. G.O. Farinu, Director of academic planning; 3, Dr. M.A. Akintonde; 4, Mr. Z.A. Adepoju, DAP office; 5, Dr. A. Lateef)

Arising from my experience, I shall like to make the following recommendations:

1. There is the need for the federal government of Nigeria to recognize microbiology as a professional course as it is the case in other climes. Thus, the bill to regulate the practice of microbiology as a profession should be passed and signed into law. This would enhance the contribution of microbiology and

the practitioners to growth and development of the country.

2. As a matter of urgency, Nigeria should establish microbial resources centres that would serve the purpose of characterization, identification, preservation and distribution of Nigerian microbial resources. This is important to preserve the microbial resources for educational, medical and industrial usage.
3. There should be concerted effort to link the biotechnology resources (BIOREC) of the National Biotechnology Development Agency (NABDA) with nearby Universities with clear mandate on research and development (R & D).
4. At the moment, nanotechnology research in Nigeria is yet to be prioritized. Therefore, there is need to develop a roadmap for nanotechnology R & D in the country that may possibly lead to the establishment of a regulatory agency on nanotechnology.
5. To play prominent roles in nanotechnology research, Nigerian government should establish centres of excellence in nanotechnology with the state-of-the-art equipment to serve as hubs of R & D in nanotechnology. To this extent, with the noble contributions of LAUTECH to nanotechnology research in Nigeria, a centre of excellence in nanotechnology is hereby canvassed for the University. In addition, I call on the Vice-Chancellor to support our quest for the establishment of Institute of Nanoscience and Nanotechnology at LAUTECH, for the essence of training postgraduate students in the emerging discipline. A proposal in this regard has been submitted to the University.

6. To popularize nanotechnology in the country, a call is hereby made for the re-engineering of curricula of science subjects and courses in such a way that its principles and applications be incorporated at high school and in higher institutions. In this direction, publication of textbooks on nanotechnology at the interface of several disciplines should be given priority by scholars.
7. Nigeria is ripe enough to engender a ranking system for Nigerian scholars as it is done for instance by the National Research Foundation of South Africa. Such ranking would facilitate access to grants; enable scholars to remain focused and also to increase their productivity.
8. The Ladoke Akintola University of Technology should revive the organization of research and development fair to stimulate research activities and serve as avenue for healthy competition among researchers. It would also serve as a medium to attract industrialists and entrepreneurs to the research products of the University, which could stimulate academia-industry partnership.
9. As a matter of urgency, I suggest that LAUTECH should establish a functional office of patent and business development to be manned by **experts**. This would enhance the business development of research outputs as well as patenting of novel discoveries and inventions.
10. The governments at all levels should endeavour to invest more in education at all strata. More is needed to be done in terms of provision of funds for research grants, acquisition of equipment, enabling atmosphere for learning and research, and improved remuneration

for scholars and allied staff. The government should be more responsible in implementation of agreements with stakeholders in the education sector to reduce the incessant and avoidable industrial crisis that often disrupt academic activities.

7.0 Appreciation

I give glory to the Almighty Allah, the Lord of the Worlds and giver of knowledge for His blessings on me since the day of my existence. Which of your favours will I deny? Certainly, none. You have bestowed on me sound knowledge, good state of mind and good health over the years. *Alhamdulillahi rabbil 'alamin*. I thank you for you brought me out as white pap from a black earthen pot! While I'm grateful for His blessings in time past, I seek refuge in Him, and pray for outstanding successes in the future.

To my father, Alhaji Lateef Àjàgún Garuba:

Àgberí ògá, omo àyórò, omo asiwo mójú le, omo ò mú arúgbó àlárúgbó lo ìgbé fi sògùn ìlàyà, kálárúgbó pa arúgbó rè mó, baba mi fé sorò ilé rè. Omo ewé kan, ògùn kan, omo ewé méjì, ògùn méjì, omo ewé méta, ògùn méta. Omo ewé gbogbo kìkí ògùn, ògùn gbogbo kìkí ewé, ògùn tí kòjé, ewé rè ló kù kan. Omo pèsè dè mí, hun ó yà lábó, omo ewé kan ni mo pè, igba ewé ló ñ jé mi lójú olo, àlògbà ni olo ìrayè. Ìlújáwé omo ajínájà ogùn. Ìlújáwé náà dà, omo ekùn náà ré o.

He is such an industrious, fearless and highly intelligent personality. He is a strict disciplinarian and community leader par excellence. And to my amiable mother, Alhaja Wosilat Àdùnké Lateef, I thank you for your efforts:

Aláayè, Omo isé l'owó, Omo ò l'óba l'órò, Omo ìjàkadì l'orò t'Offà,..... Ìyèrú Òkín, Omo 'lááre, Omo bú re, ìkan ò gbodò jù kàn, bí kan bá jù kan nílé Olófàmojò, ogun lón'dá ní ilé baba won.....ìyá mi Olófàmojò..... Omo Odéwolé, Omo Olúbùnmi, Omo Ògúnmódedé....

I thank the management of my alma mater, Ladoke Akintola University of Technology, Ogbomoso for the investments in my career; particularly the granting of study leave, research grant and provision of materials to undertake some of the works mentioned in this lecture. I appreciate the sacrifice and doggedness of our foundation Vice-Chancellor, Prof. O.L. Oke *FAS* to train us with some of the best hands available in the country. I was stimulated research-wise through his thought provoking lecture on cassava as source of food and death trap, which he delivered at the Nigerian Institute of International Affairs (NIIA) Lagos during the investiture of fellows of the Nigerian Academy of Science (NAS) in 1991. I was among the selected students that attended the lecture.

Late Prof. A.M. Salau *FAS* (of blessed memory) employed me as part of the first set of graduates of LAUTECH as a graduate assistant in 1998. He also contributed immensely to the CSIR/TWAS postgraduate fellowship that I got in 2003. It was during the tenure of Prof. B.B. Adeleke that I obtained PhD, became Senior Lecturer and he also nominated me into the board of consultancy services of LAUTECH, where I sat with the Chairman of the selection panel that interviewed me in 1998, Prof. O.O.P. Faboya. He also approved my sabbatical leave in 2008, and I was part of the team that represented the University at four research and development fairs during his tenure. Thank you, Sir.

I appreciate the love shown to me by the immediate past Vice-Chancellor, Professor A.S. Gbadegesin. I won't forget that it was under your tenure that I became Reader, Professor, Acting Head of Department of Science Laboratory Technology, Head of Department of Pure and Applied Biology, elected representative of Senate on LAUTECH Governing Council, and Chairman of the Management Committee of the Central University Research Laboratory. He provided the necessary stimulus in encouraging the nanotechnology research group in both official and personal capacities. The current Vice-Chancellor and my teacher, Prof. M.O. Ologunde *FNIFST,* I thank you, Sir for appointing me as the Director/Chief Scientist of the Central University Research Laboratory and other responsibilities placed on my shoulders.

To all my teachers; too numerous to mention, I appreciate your efforts in imparting knowledge to me. Specifically, I thank my mentor and supervisor, Professor Julius Kola Oloke, *NNOM,* for his love, care and sound training that I received under his tutelage. To Professors M.A. Osundina, O.O. Fawole, M.O. Liasu, O.O. Oyegoke, A.T.J Ogunkunle, and A.J. Akintola for your mentorship. I am grateful for the working relationship with Prof. S.O. Adewoye, Dr. A.A. Ayandele, Dr. A. Akinboro, Dr. O.O. Ajala, Dr. E.A. Adebayo, Dr. I.O. Omomowo, Dr. O.N. Majolagbe, Dr. A.F. Ogundola, Dr. M.A. Ogundiran, Dr. T.A. Ayandiran, Dr. C.O. Bamigboye and all the technical and administrative members of staff of the Department of Pure and Applied Biology, and the Central Research Laboratory, LAUTECH, Ogbomoso. I thank you for your constant support. In the same token, I thank all members of staff of the Department of Science Laboratory Technology, LAUTECH for their cooperation while I headed the

department. I must recognize Prof. A.A. Bakare of the Department of Zoology, University of Ibadan for his mentorship. He introduced me to international publishing having jointly published a paper (Bakare *et al.*, 2003).

I must appreciate the past and current leaders of the Faculty of Pure and Applied Sciences for putting the faculty as the first amongst her peers. I appreciate Late Prof. A.O. Lawanson, Prof. A.O. Alabi, Prof. O.O.P. Faboya, Late Prof. R.O. Ayeni, Prof. O.A. Odunola, Prof. O.O. Fawole, Prof. E.T. Ayodele, and Prof. O.M. Oni for their contributions to my academic growth as a student and member of staff since 1990. The current Dean, Prof. A.T. Oladipo has placed a lot of responsibilities on me to chair several committees and also deliver talks in the last two years. He has also shown exceptional interest in me and supported my research activities on nanotechnology in both private and official capacities. I thank you, Sir. Greater heights by God's grace.

I thank all Professors, Provost, College of Health Sciences, Dean of Postgraduate School, Deans of Faculties, Ag. Dean of Students' Affairs, Heads of Departments and Directors of academic centres and programmes for the confidence reposed in me to be elected as the first alumnus of this University to represent Senate on the Governing Council of LAUTECH. I wish to place on record, the love that have been shown to us by my former teacher and the Pro-Chancellor/Chairman of the Governing Council of LAUTECH, Prof. Oladapo O. Afolabi *OON, CFR,* whose words of encouragement and encomium have defined me at high places. It was a great honour to sit with you, Sir on the Governing Council of this University. In the same token, I thank all members of the council for their healthy working relationships.

To my special friends, colleagues and confidants, Prof. E.B. Gueguim-Kana (now in South Africa), Prof. M.A. Azeez, and Prof. T.A. Yekeen I cannot thank you enough for your true friendship and the Spartan lifestyle that has defined us over the years. I thank Dr. T.B. Asafa and all my friends within the University and beyond.

I wish to appreciate all members of my research family, the LAUTECH Nanotechnology Research Group ($NANO^{+}$) for their commitments to the aspirations of the group, and for accepting me to lead the group thus far, despite my shortcomings. Your resilience always put me on the spot that we must not fail. I'm grateful to you for tolerating my excesses and for overlooking my weaknesses.

I have received supports from several individuals and organizations in my academic pursuits which are too numerous to mention. To my collaborators in Nigeria, India, South Africa, Egypt, Italy, Sweden, and Saudi Arabia, I appreciate your scholarly contributions. I must recognize Prof. E.B. Gueguim-Kana, Dr. S.G. Prapulla (Rtd), Dr. L.S. Beukes, Dr. A.S. Hakeem, Dr. N. Dasgupta, and Dr. L.A. Azeez among others. Similarly, I appreciate the support of various organizations such as TWAS (Italy), CSIR (India), TETFund (Nigeria), Fondaziole Cariplo (Italy), NRF (South Africa), Nigerian Young Academy (Nigeria), NUC (Nigeria) and Federal Ministry of Science and Technology, Abuja (Nigeria) for the recognition and support for my research activities.

In my academic journey, I have received supports from senior colleagues from within and outside LAUTECH. I appreciate Prof. H.O.B. Oloyede, the foundation Vice-Chancellor of both Fountain University, Osogbo and Summit University, Offa for playing the role of academic father in my life. I must appreciate

distinguished scholars at University of Ibadan, Ibadan, University of Ilorin, Ilorin, Federal University of Agriculture, Abeokuta, Babcock University, Ilishan-Remo, Al-Hikmah University, Ilorin, Ajayi Crowther University, Oyo and other Universities in India and South Africa where I have served as external examiners for the recognition of my expertise. At Fountain University, Osogbo, and Summit University, Offa where I have assisted in teaching, I thank you for the healthy working relationships.

To all my students; past and present, it has been a wonderful journey together. I thank you for your perseverance. The list is endless but I take representatives such as Mrs. O.R. Raimi, Mr. I.A. Adelere, Mr. A.O. Adeoye, Mr. S.A. Ojo, Mr. J.A. Elegbede, Mr. P.O. Akinola, and Mrs. V.A. Ajayi to appreciate the good work that you have done and still doing.

I am a man of different parts and moderately sociable. I have affiliations with some organizations that have contributed to my total being. I therefore thank Afrique Club of Apomu, LAUTECH Muslim Community (LMC), LAUTECH Muslim Graduates' Association (LAUMGA), LAUTECH Alumni Association, particularly the 90-92 sets, Apomu Council of Youths (ACOY), and Apomu Descendants' Union (ADU) for the privilege to be one of you and the opportunities to serve mankind. I sincerely thank all members of African Church Grammar School, Apomu Old Students' Association (AFROGOSA) for the confidence reposed in me as the President of the association to reposition our former school. I also thank the government of Osun state for my appointment as the Chairman, Board of Governors of the school. I must not forget to thank the class '88 of the school to which I belong and my friends; Mrs. Olubukola O. Akinpelu, Mr.

Munirudeen O. Arilesere, Mr. Akeem Ojewale, Alh. Akeem O. Moronfade, and Mr. Rotimi Rufai among others. In that secondary school, I had the rare privilege of being mentored by some of my seniors, among which are Prof. Memudu O. Olaposi, Dr. Musefiu A. Tiamiyu, Dr. Fasilat B. Olalere, Mr. Akinwunmi Akinola, Mr. Kazeem A. Sunmonu, Mr. Muritala O. Ayandare, Engr. Bola Saheed, and Mr. Johnson Babatunde (*FCIB*) among others. I thank you for holding forth as our teachers.

In my efforts to give back to my community, I have been involved in developmental programmes through Apomu Descendants' Union under the leadership of Oluomo (Engr.) Soliu Abass where I currently serve as the Chairman of the Education Development Committee. I appreciate the leadership role of the President-General and the executives for the zeal of transforming Apomu into an enviable kingdom. I must place on record the love shown to me by a father, the legendary and doyen of community development in Apomu, Asiwaju (Alhaji) Olaitan Alabi for his supports and words of encouragement at all times.

I use this opportunity to thank all my fathers, mothers, uncles and sisters from Apomu for their supports and prayers over the years. Alhaji (Chief) Adiatu Oyetayo, Chief Akeeb Ogunmodede, Mrs. Modinatu Adewole, Chief Waheed Ogunmodede, Mr. Asimiyu Ogunmodede, Late (Mrs.) Aduke Olanrewaju, Chief Ambaliyu Adebamini, Alhaji Adeshina Hassan (Shina Ekun), Alhaja Bushirat Olalere, Mrs. Alimot Babatowo, Chief Nasiru Jimoh (Omo Oloriire), Alhaji (Hon.) Rasheed Ogundipe, Mrs. Monsurat Lateef among others. To my siblings and cousins; Late Mrs. Saudat Ibrahim, Jelilat, Alhaji Nurudeen Alowonle, Abdul-Rahman, Subedat, Kehinde, Toyyib, Morufat,

Morufdeen, Ibrahim and Yesirat, I thank you for the love and your prayers.

To the '*Oko Ìlú',* my royal father, Kabiyesi, His Royal Majesty, Oba Kayode Adenekan Afolabi (Atoyebi II), the Alapomu of Apomu kingdom, I want to specially appreciate your supports and prayers. Within a very short time, the transformation in Apomu kingdom is visible to everyone. May your reign be long, peaceful and prosperous. I must appreciate your amiable wife, Olori Mba Janet Afolabi for her untiring love for the progress of women and children of Apomu. I extend the appreciation to all the High Chiefs, Baloguns, spiritual leaders and the nobles of Apomu for their good wishes.

Figure 47: With Kabiyesi, HRM Oba Kayode Adenekan Afolabi (Atoyebi II), The Alapomu of Apomu Kingdom and Asiwaju Olaitan Alabi during the flag off exercise of distribution of palliatives of Apomu COVID-19 Relief Project on 20 April, 2020 (where I served as the secretary of the relief committee)

I sincerely appreciate my in-laws; Alhaji (late) Rauf and Mama Rafat Abdullahi. May Allah grant baba aljanah firdaus (paradise) and strengthen the life of mama for us. To all the immediate and extended members of the family, you are kindly appreciated for your supports.

I will not end this lecture, without paying homage to my primary constituency, the life-line of academic rubicon in Nigeria, the Academic Staff Union of Universities (ASUU) for consistently engaging the governments to improve the landscape of education in Nigeria. I recognize our past heroes and current comrades in struggles. I must appreciate Prof. Omotoye Olorode, Prof. Idowu Awopetu and Prof. Poju Akinyanju all of whom are biologists. I have drawn from their fountains of knowledge both academically and in struggles. At LAUTECH chapter, I recognize the veterans and our leaders; Late Prof. B.A. Oyelere, Prof. G.O. Farinu, Kabiyesi (Prof.) A.J. Akintola, Prof. T.A. Adejumo, Dr. M.O. Okelola, Prof. O.O. Oyegoke (baba kékeré), and Dr. O.A. Olaniran for providing the leadership for a common front for the good of all at LAUTECH, Ogbomoso.

Finally, I thank my wife, Anifat Omowumi and the children for their love, understanding and perseverance at all times. You have sacrificed greatly for me to reach the peak of my career, which is deeply appreciated. AbdusSalaam Taiwo and AbdusSataar Kehinde (*èjìré ará ìsokùn*) and Islamiyah Idowu, we are proud of you always. To you, I dedicate this lecture.

I thank you all for your presence. May God bless you, and grant you journey mercies to your various destinations.

References

ACS (2020). Nanochemistry. https://www.acs.org/content/acs/en/careers/college-to-career/chemistry-careers/nanochemistry.html (Accessed on 15 March, 2020).

Adebayo, E.A., Ibikunle, J.B., Oke, A.M., **Lateef, A**., Azeez, M.A., Oluwatoyin, A.O., Ajala V.A., Olowoporoku T.B., Okunlola O.C., Ogundele O.A., Badmus, J.A., Asafa, T.B., Beukes, L.S., Gueguim-Kana, E.B., and Abbas S.H. (2019b). Antimicrobial and antioxidant activity of silver, gold and silver-gold alloy nanoparticles phytosynthesized using extract of *Opuntia ficus-indica. Reviews on Advanced Materials Science* **58** (1): 313-326.

Adebayo, E.A., Oke, A.M., **Lateef, A**., Oyatokun, A.A., Abisoye, O.D., Adiji, I.P., Fagbenro, D.O., Amusan, T.V., Badmus, J.A., Asafa, T.B., Beukes, L.S., Gueguim-Kana, E.B., and Abbas, H.S. (2019a). Biosynthesis of silver, gold and silver-gold alloy nanoparticles using *Persea americana* fruit peel aqueous extract for their biomedical properties. *Nanotechnology for Environmental Engineering* **4**: 13. https://doi.org/10.1007/s41204-019-0060-8.

Adebayo, E.A., Oladipo, I.C., Badmus, J.A., and **Lateef, A**. (2021). Beneficial microbes as novel microbial cell factories in nanobiotechnology: potentials in nanomedicine. In: Lateef, A., Gueguim-Kana, E.B., Dasgupta, N., and Ranjan, S. (Eds.). *Microbial Nanobiotechnology: Principles and Applications.* Springer Nature Singapore Pte. Ltd.

ISBN 978-981-334-777-9. https://doi.org/10.1007/978-981-33-4777-9_11.

Adebisi, J.A., Olabemiwo, O.M., Adeoye, I.O., and **Lateef, A**. (2002). Assessment of drinking water in Igbeti using coliform test. *Science Focus* **1**: 47-49.

Adelere, I.A and **Lateef, A**. (2016b). A novel approach to the green synthesis of metallic nanoparticles: the use of agro-wastes, enzymes and pigments. *Nanotechnology Reviews* **5** (6): 567-587.

Adelere, I.A., and **Lateef, A**. (2016a). Keratinases: emerging trends in production and applications as novel multifunctional biocatalysts. *Kuwait Journal of Science* **43** (3): 118-127.

Adelere, I.A., and **Lateef, A**. (2019). Degradation of keratin biomass by different microorganisms. In: Sharma, S., and Kumar, A. (Eds.). *Keratin as a Protein Biopolymer*. Springer Series on Polymer and Composite Materials. https://doi.org/10.1007/978-3-030-02901-2_5. Springer International Publishing AG, Cham, Switzerland. ISBN 978-3-030-02900-5. Pp. 123-162.

Adelere, I.A., and **Lateef, A**. (2021). Microalgal nanobiotechnology and its applications—a brief overview. In: Lateef, A., Gueguim-Kana, E.B., Dasgupta, N., and Ranjan, S. (Eds.). *Microbial Nanobiotechnology: Principles and Applications.* Springer Nature Singapore Pte. Ltd. ISBN 978-981-334-777-9. https://doi.org/10.1007/978-981-33-4777-9_8.

Adelere, I.A., **Lateef, A**., Aboyeji, D.O., Abdulsalam, R., Adabara, N.U., and Bala, J.D (2017). Biosynthesis of silver nanoparticles using aqueous extract of

Buchholzia coriacea (wonderful kola) seeds and their antimicrobial activities. *Annals Food Science and Technology* 18: 671-679.

Adeleye, O.A., Badru, A.O., Oyinloye, O.E., Fagbohun, A.B., Bakre, L.G., Bamiro, O.A., Babalola, C.O., and **Lateef, A**. (2020). Green synthesized silver nanoparticles for cream formulation, its anti-inflammatory and healing activities. *IOP Conference Series: Materials Science and Engineering* **805**: 012016. https://doi.org/10.1088/1757-899X/805/1/012016.

Adeoye, A.O., Akande, E.A., and **Lateef, A**. (2018). Impacts of hospital waste management on the health and environment of Ogbomoso area, Oyo state. *Hospice and Palliative Medicine International Journal* **2** (6): 386-389.

Adeoye, A.O., **Lateef, A**., and Gueguim-Kana, E.B. (2015). Optimization of citric acid production using a mutant strain of *Aspergillus niger* on cassava peel substrate. *Biocatalysis and Agricultural Biotechnology* **4** (4): 568-574.

Adewoye, S.O., and **Lateef, A**. (2004a). Evaluation of the microbiological characteristics of Oyun River – a polluted river in North-Central Nigeria. *Pollution Research* **23** (4): 587-591.

Adewoye, S.O., and **Lateef, A**. (2004b). Assessment of the microbiological quality of *Clarias gariepinus* exposed to an industrial effluent in Nigeria. *The Environmentalist (now Environment Systems and Decisions)* **24**: 249-254.

Agarwal, H., Kumar, S.V., and Rajeshkumar, S. (2017). A review on green synthesis of zinc oxide

nanoparticles–An eco-friendly approach. *Resource-Efficient Technologies* **3** (4): 406-413.

Aina, A.D., Owolo, O., Adeoye-Isijola, M., Amodu, S., Olukanni, O.D., Aina, F.O., **Lateef, A**., and Adediji, I. (2018). Mycosynthesis of silver nanoparticles using *Lentinus squarrosulus* and its antibacterial activities. *Science Focus* **23** (2): 44-54.

Aina, A.D., Owolo, O., Adeoye-Isijola, M., Olukanni, O.D., **Lateef, A**., Egbe, T., Aina, F.O., Asafa, T.B., and Abbas, S.H. (2020) Ecofriendly production of silver nanoparticles from the seeds of *Carica papaya* and its larvicidal and antibacterial efficacy against some selected bacterial pathogens. *IOP Conference Series: Materials Science and Engineering* **805**: 012038. https://doi.org/10.1088/1757-899X/805/1/012038.

Aina, D.A., Owolo, O., **Lateef, A**., Aina, F.O., Abbas, S.H., Adeoye-Isijola, M., Okon, V., Asafa, T.B., Elegbede, J.A., Olukanni, O.D., and Adediji, I. (2019). Biomedical applications of *Chasmanthera dependens* stem extract mediated silver nanoparticles as antimicrobial, antioxidant, anticoagulant, thrombolytic, and larvicidal agents. *Karbala International Journal of Modern Science* **5**: 71-80.

Akinola, P.O., **Lateef, A**., Asafa, T.B., Beukes, L.S., Hakeem A.S., and Irshad, H.M. (2020). Multifunctional titanium dioxide nanoparticles biofabricated via phytosynthetic route using extracts of *Cola nitida*: antimicrobial, dye degradation, antioxidant and anticoagulant activities. *Heliyon* **6** (8): e04610.

Akintayo, G.O., **Lateef, A**., Azeez, M.A., Asafa, T.B., Oladipo, I.C., Badmus, J.A., Ojo, S.A., Elegbede, J.A., Gueguim-Kana, E.B., Beukes, L.S., and Yekeen, T.A. (2020) Synthesis, bioactivities and cytogenotoxicity of animal fur-mediated silver nanoparticles. *IOP Conference Series: Materials Science and Engineering* **805**: 012041. https://doi.org/10.1088/1757-899X/805/1/012041.

Allahverdiyev, A.M., Kon, K.V., Abamor, E.S., Bagirova, M., and Rafailovich, M. (2011). Coping with antibiotic resistance: combining nanoparticles with antibiotics and other antimicrobial agents. *Expert review of anti-infective therapy* **9** (11): 1035-1052.

Allied Market Research (2014). Nano titanium dioxide market by application (paints & coatings, pigments, cosmetics, plastics, energy and others) - global opportunity analysis and industry forecast, 2014-2022. https://www.alliedmarketresearch.com/nano-titanium-dioxide-market (Accessed on 15 March, 2020).

Amani, H. (2017). Synergistic effect of biosurfactant and nanoparticle mixture on microbial enhanced oil recovery. *Journal of Surfactants and Detergents* **20** (3): 589-597.

Araromi, D.O., and **Lateef, A**. (2005). Xanthan gum production by wild-type isolate of *Xanthomonas campestris* in whey-based medium. *Research Communications in Microbiology* **1** (3): 1-5.

Asafa, T.B., Odusote, J.K., Ibrahim, O.S., **Lateef, A**., Durowoju, M.O., Azeez, M.A., Yekeen, T.A., Oladipo, I.C., Adebayo, E.A., Badmus, J.A., Sanusi, Y.K., and Adedokun, O. (2020).

Inhibition efficiency of silver nanoparticles solution on corrosion of mild steel, stainless steel and aluminum in 1.0 M HCl medium. *IOP Conference Series: Materials Science and Engineering* **805**: 012018. https://doi.org/10.1088/1757-899X/805/1/012018.

Asafa, T.B., Odediji, R.A., Salaudeen, T.O., **Lateef, A**., Durowoju, M.O., Azeez, M.A., Yekeen, T.A., Oladipo, I.C., Irshad, M., and Abbas, S.H. (2021). Physico-mechanical properties of emulsion paint embedded with silver nanoparticles. *Bulletin of Materials Science* **44**: 7. https://doi.org/10.1007/s12034-020-02282-5.

Ashton, J. (2020). The pandemic of coronavirus: tackling the latest plague. *Journal of the Royal Society of Medicine* **113** (3): 123-124.

Atanda, O.O., Ogunrinu, M.C., and Olorunfemi, F.M (2011). A neutral red dessicated coconut agar for rapid detection of aflatoxigenic fungi and visual determination of aflatoxins. *World Mycotoxin Journal* **4**: 147-155.

Ayukekbong, J.A., Ntemgwa, M., and Atabe, A.N. (2017). The threat of antimicrobial resistance in developing countries: causes and control strategies. *Antimicrobial Resistance and Infection Control* **6**: 47. https://doi.org/10.1186/s13756-017-0208-x.

Azeez, L., Adejumo, A.L., **Lateef, A**., Adebisi, S.A., Adetoro, R.O., Adewuyi, S., Tijani, K.O., and Olaoye, S. (2019c). Zero-valent silver nanoparticles attenuate Cd and Pb toxicities on *Moringa oleifera* via immobilization and induction

of phytochemicals. *Plant Physiology and Biochemistry* **139**: 283-292.

Azeez, L., Adejumo, A.L., Ogunbode, S.M., **Lateef, A**., and Adetoro, R.O. (2020c). Influence of calcium nanoparticles (CaNPs) on nutritional qualities, radical scavenging attributes of *Moringa oleifera* and risk assessments on human health. *Journal of Food Measurement and Characterization* **14** (4): 2185-2195.

Azeez, L., **Lateef, A**., Adebisi, S.A., and Oyedeji, A.O. (2018). Novel biosynthesized silver nanoparticles from cobweb as adsorbent for Rhodamine B: equilibrium isotherm, kinetic and thermodynamic studies. *Applied Water Science* **8**: 32. https://doi.org/10.1007/s13201-018-0676-z.

Azeez, L., **Lateef, A**., Adejumo, A.L., Adeleke, J.T., Adetoro, R.O., and Mustapha, Z. (2020a). Adsorption behaviour of Rhodamine B on hen feather and corn starch functionalized with green synthesized silver nanoparticles (AgNPs) mediated with cocoa pods extracts. *Chemistry Africa* **3**: 237-250.

Azeez, L., **Lateef, A**., and Adebisi, S.A. (2017b). Silver nanoparticles (AgNPs) biosynthesized using pod extract of *Cola nitida* enhances antioxidant activity and phytochemical composition of *Amaranthus caudatus* Linn. *Applied Nanoscience* **7** (1-2): 59-66.

Azeez, L., **Lateef, A**., Wahab, A.A., Adejumo, A.L., and Raji, K. (2019b). Comparative effects of silver nanoparticles, sucrose and sodium chloride as osmotic solutions for tomato slices: antioxidant activity, microbial quality and modelling with

polynomial regression model. *South African Journal of Chemistry* **72**: 21-31.

Azeez, L., **Lateef, A**., Wahab, A.A., Rufai, M.A., Salau, A.K., Ajayi, I.O., Ajayi, E.M., Maryam, A.K., and Adebisi, B. (2019a). Phytomodulatory effects of silver nanoparticles on *Corchorus olitorius*: its antiphytopathogenic and hepatoprotective potentials. *Plant Physiology and Biochemistry* **136**: 109-117.

Azeez, M.A., **Lateef, A**., Asafa, T.B., Yekeen, T.A., Akinboro, A., Oladipo, I.C., Gueguim-Kana, E.B., and Beukes, L.S. (2017a). Biomedical applications of cocoa bean extract-mediated silver nanoparticles as antimicrobial, larvicidal and anticoagulant agents. *Journal of Cluster Science* **28** (1): 149-164.

Azeez, M.A., Durodola, F.A., **Lateef, A**., Yekeen, T.A., Adubi, A.O., Oladipo, I.C., Adebayo, E.A., Badmus, J.A., and Abawulem, A.O. (2020b). Green synthesized novel silver nanoparticles and their application as anticoagulant and thrombolytic agents: A perspective. *IOP Conference Series: Materials Science and Engineering* **805**: 012043. https://doi.org/10.1088/1757-899X/805/1/012043.

Badmus, J.A., Oyemomi, S.A., Adedosu, O.T., Yekeen, T.A., Azeez, M.A., Adebayo, E.A., **Lateef, A**., Badeggi, U.M., Botha, S., Hussein, A.A., and Marnewick, J.L. (2020). Photo-assisted bio-fabrication of silver nanoparticles using *Annona muricata* leaf extract: exploring the antioxidant, anti-diabetic, antimicrobial, and cytotoxic activities. *Heliyon* **6** (11): e05413. https://doi.org/10.1016/j.heliyon.2020.e05413.

Bakare, A.A., **Lateef, A**., Amuda, O.S., and Afolabi, R.O. (2003). The aquatic toxicity and characterization of chemical and microbiological constituents of water samples from Oba River, Odo-Oba, Nigeria. *Asian Journal of Microbiology, Biotechnology and Environmental Sciences* **5** (1): 11-17.

Bamigboye, C.O., Oloke, J.K., Dames, J.F., Burton, M., and **Lateef, A**. (2019). Optimization of the process for producing biomass and exopolysaccharide from the King tuber oyster mushroom, *Pleurotus tuber-regium* (Agaricomycetes), for biotechnological applications. *International Journal of Medicinal Mushrooms* **21** (4): 311-322.

Banigo, A.T., Azeez, T.O., Ejeta, K.O., **Lateef, A**., and Ajuogu, E. (2020). Nanobiosensors: applications in biomedical technology. *IOP Conference Series: Materials Science and Engineering* **805**: 012028. https://doi.org/10.1088/1757-899X/805/1/012028.

Batta, H., Ashong, C., and Obot, C. (2014). Science, nano-science and nano-technology content in nigeria's elite and popular press: Focus on framing and socio-political involvement. *New Media and Mass Communication* **31**: 9-19.

BCC Research (2014a). Nanoparticles in biotechnology, drug development and drug delivery. https://www.bccresearch.com/market-research/biotechnology/nanoparticles-biotechnology-drug-development-drug-delivery-report.html (Accessed on 8 March, 2020).

BCC Research (2014b). Nanotechnology in printing: Global markets. https://www.bccresearch.com/market-

research/nanotechnology/nanotechnology-printing-report.html (Accessed on 14 March, 2020).

BCC Research (2014c). Nanoparticles in biotechnology, drug development and drug delivery. https://www.bccresearch.com/market-research/biotechnology/nanoparticles-biotechnology-drug-development-drug-delivery-report.html (Accessed on 15 March, 2020).

BCC Research (2015). Nanotechnology in environmental applications: The global market. https://www.bccresearch.com/market-research/nanotechnology/nanotechnology-environmental-applications-market.html (Accessed on 14 March, 2020).

BCC Research (2017a). Biorefinery products: Global markets. https://www.bccresearch.com/market-research/energy-and-resources/biorefinery-products-markets-report.html (Accessed on 4 March, 2020).

BCC Research (2017b). Nanotechnology in medical applications: The global market. https://www.bccresearch.com/market-research/healthcare/nanotechnology-medical-applications-market.html (Accessed 14 March, 2020).

BCC Research (2018a). Global market for probiotics to reach $57.2 billion by 2022. https://www.bccresearch.com/pressroom/fod/global-market-for-probiotics-to-reach-$572-billion-by-2022 (Accessed on 4 March, 2020).

BCC Research (2018b). Global human insulin market. https://www.bccresearch.com/partners/verified-

market-research/global-human-insulin-market.html (Accessed on 4 March, 2020).

BCC Research (2018c). Nanodevices and nanomachines: The global market. https://www.bccresearch.com/market-research/nanotechnology/nanodevices-and-nanomachines-market-report.html (Accessed on 14 March, 2020).

BCC Research (2019). Nanotechnology and advanced materials research review. https://www.bccresearch.com/market-research/nanotechnology/nanotechnology-fuel-cell-research-review.html (Accessed on 14 March, 2020).

BCC Research (2020). Global citric acid market - Premium insight, competitive news feed analysis, company usability profiles, market sizing & forecasts to 2025. https://www.researchandmarkets.com/reports/4989586/global-citric-acid-market-premium-insight#rela3-338581 (Accessed on 4 March, 2020).

Bellotti, N., Romagnoli, R., Quintero, C., Domínguez-Wong, C., Ruiz, F., and Deyá, C. (2015). Nanoparticles as antifungal additives for indoor water borne paints. *Progress in Organic Coatings* **86**: 33-40.

Beyer, P., Al-Babili, S., Ye, X., Lucca, P., Schaub, P., Welsch, R., and Potrykus, I. (2002). Golden rice: introducing the β-carotene biosynthesis pathway into rice endosperm by genetic engineering to defeat vitamin A deficiency. *The Journal of Nutrition* **132** (3): 506S-510S.

Brundage, J.F., and Shanks, G.D. (2008). Deaths from bacterial pneumonia during 1918–19 influenza pandemic. *Emerging Infectious Diseases* **14** (8): 1193-1199.

Buchholz, K., and Collins, J. (2013). The roots—a short history of industrial microbiology and biotechnology. *Applied Microbiology and Biotechnology* **97** (9): 3747-3762.

Carvalho, F., George, J., Sheikh, H.M.A., and Selvin, R. (2018). Advances in screening, detection and enumeration of *Escherichia coli* using nanotechnology-based methods: a review. *Journal of Biomedical Nanotechnology* **14** (5): 829-846.

Chadha, B.S. (2019). Industrial Microbiology: Current Status of Research & Development in India. *Proceedings of the Indian National Science Academy* **85** (4): 949-961.

Chopra, N.K., Ni, H., and Lim, V. (2019). Past Present and Future Status of HIV-AIDS Pandemic Problem in World. *Microbiology and Infectious Diseases* **3** (1): 1-6.

City Mirror (2017). Despite varsity closure, LAUTECH set to lead Nigeria in nanotechnology. http://citymirrornews.com/top-news/2017/18/despite-varsity-closure-lautech-set-to-lead-nigeria-in-nanotechnology/ (Accessed on 18 July, 2017).

City Voice (2018). Science minister indicates govt support for nanotechnology at LAUTECH 2018. http://cityvoiceng.com/science-minister-indicates-govt-support-for-nanotechnology-at-lautech-2018/ (Accessed on 30 October, 2018).

Cox, G., and Wright, G.D. (2013). Intrinsic antibiotic resistance: mechanisms, origins, challenges and solutions. *International Journal of Medical Microbiology* **303** (6-7): 287-292.

Cummings, J.H., and Stephen, A.M. (2007). Carbohydrate terminology and classification. *European Journal of Clinical Nutrition* **61** (1): S5-S18.

Daily Independent (2018). Minister tasks researchers, institutes on product-centered studies. Daily Independent, Lagos, Nigeria, Nov. 19, 2018; pg. 5. https://www.independent.ng/minister-tasks-researchers-institutes-on-product-centered-studies/ (Accessed on 19 November, 2018).

Davison, H.C., Woolhouse, M.E., and Low, J.C. (2000). What is antibiotic resistance and how can we measure it? *Trends in Microbiology* **8** (12): 554-559.

Dean, K.R., Krauer, F., Walløe, L., Lingjærde, O.C., Bramanti, B., Stenseth, N.C., and Schmid, B.V. (2018). Human ectoparasites and the spread of plague in Europe during the Second Pandemic. *Proceedings of the National Academy of Sciences* **115** (6): 1304-1309.

Demain, A.L. (2007). REVIEWS: The business of biotechnology. *Industrial Biotechnology* **3** (3): 269-283.

Demain, A.L., and Adrio, J.L. (2008). Contributions of microorganisms to industrial biology. *Molecular Biotechnology* **38**: 41. https://doi.org/10.1007/s12033-007-0035-z.

Demain, A.L., and Vaishnav, P. (2009). Production of recombinant proteins by microbes and higher

organisms. *Biotechnology Advances* **27** (3): 297-306.

Drexler, E.K. (1986). Engines of Creation. The Coming Era of Nanotechnology. *Anchor Book.*

Durán, N., Durán, M., De Jesus, M.B., Seabra, A. B., Fávaro, W.J., and Nakazato, G. (2016). Silver nanoparticles: A new view on mechanistic aspects on antimicrobial activity. *Nanomedicine: Nanotechnology, Biology and Medicine* **12** (3): 789-799.

Economou, V., and Gousia, P. (2015). Agriculture and food animals as a source of antimicrobial-resistant bacteria. *Infection and Drug Resistance* **8**: 49-61.

Elegbede, J.A., and **Lateef, A**. (2018). Valorization of corn-cob by fungal isolates for production of xylanase in submerged and solid state fermentation media and potential biotechnological applications. *Waste and Biomass Valorization* **9** (8): 1273-1287.

Elegbede, J.A., and **Lateef, A**. (2019a). Green nanotechnology in Nigeria: The research landscape, challenges and prospects. *Annals of Science and Technology* **4** (2): 6-38.

Elegbede, J.A., and **Lateef, A**. (2019b). Optimization of the production of xylanases in corncob-based media by *Aspergillus niger* and *Trichoderma longibrachiatum* using Taguchi approach. *Acta Biologica Szegediensis* **63** (1): 51-58.

Elegbede, J.A., and **Lateef, A**. (2019c). Green synthesis of silver (Ag), gold (Au) and silver-gold (Ag-Au) alloy nanoparticles: A review on recent advances, trends and biomedical applications. In: Verma, D.K., Goyal, M.R., and Suleria, H.A.R. (Eds.). *Nanotechnology and Nanomaterial Applications in*

Food, Health and Biomedical Sciences. https://doi.org/10.1201/9780429425660-1 . Apple Academic Press Inc. /CRC Press, Taylor and Francis Group, Oakville, Ontario, Canada. ISBN 978-1-77188-764-9. Pp. 3-89.

Elegbede, J.A., and **Lateef, A**. (2020). Nanotechnology in the built environment for sustainable development. *IOP Conference Series: Materials Science and Engineering* **805**: 012044. https://doi.org/10.1088/1757-899X/805/1/012044.

Elegbede, J.A., and **Lateef, A**. (2021). Microbial enzymes in nanotechnology and fabrication of nanozymes: a perspective. In: Lateef, A., Gueguim-Kana, E.B., Dasgupta, N., and Ranjan, S. (Eds.). *Microbial Nanobiotechnology: Principles and Applications.* Springer Nature Singapore Pte. Ltd. ISBN 978-981-334-777-9. https://doi.org/10.1007/978-981-33-4777-9_7.

Elegbede, J.A., **Lateef, A**., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Oladipo, I.C., Aina, D.A., Beukes, L.S., and Gueguim-Kana, E.B (2020). Biofabrication of gold nanoparticles using xylanases through valorization of corncob by *Aspergillus niger* and *Trichoderma longibrachiatum*: antimicrobial, antioxidant, anticoagulant and thrombolytic activities. *Waste and Biomass Valorization* **11** (3): 781-791.

Elegbede, J.A., **Lateef, A**., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Oladipo, I.C., Abbas, S.H., Beukes, L.S., and Gueguim-Kana, E.B. (2019). Silver-gold alloy nanoparticles biofabricated by fungal xylanases exhibited potent biomedical and catalytic

activities. *Biotechnology Progress* **35**: e2829. https://doi.org/10.1002/btpr.2829.

Elegbede, J.A., **Lateef, A**., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Oladipo, I.C., Adebayo, E.A., Beukes, L.S., and Gueguim-Kana, E.B (2018). Fungal xylanases-mediated synthesis of silver nanoparticles for catalytic and biomedical applications. *IET Nanobiotechnology* **12** (6): 857-863.

Espitia, P.J.P., Soares, N.D.F.F., dos Reis Coimbra, J.S., de Andrade, N.J., Cruz, R.S., and Medeiros, E.A.A. (2012). Zinc oxide nanoparticles: synthesis, antimicrobial activity and food packaging applications. *Food and Bioprocess Technology* **5** (5): 1447-1464.

Ezejiofor, T.I.N., Enebaku, U.E., and Ogueke, C. (2014). Waste to wealth-value recovery from agro-food processing wastes using biotechnology: a review. *Biotechnology Journal International* **4** (4): 418-481.

Fawole, O.O., **Lateef, A**., and Amaefuna, M. (2002). Microbiological examination of drinking water in Ogbomoso metropolis, Southwest, Nigeria. *Science Focus* **1**: 16-20.

Fedson, D.S. (2019). Treating the host response: an alternative way to manage Ebola in Africa and the next influenza pandemic. *Journal of Global Health* **9** (1): 010322. https://doi.org/10.7189/jogh-09-010322.

Feynman, R.P. (1960). There's plenty of room at the bottom. *California Institute of Technology Journal of Engineering and Science* **4** (2): 23-36.

Fonteles, T., and Rodrigues, S. (2018). Prebiotic in fruit juice: processing challenges, advances, and perspectives. *Current Opinion in Food Science* **22**: 55-61.

Ganaie, M.A., **Lateef, A.**, and Gupta, U.S. (2014). Enzymatic trends of fructooligosaccharides production by microorganisms. *Applied Biochemistry and Biotechnology* **172** (4): 2143-2159.

Gandra, S., Barter, D.M., and Laxminarayan, R. (2014). Economic burden of antibiotic resistance: how much do we really know? *Clinical Microbiology and Infection* **20** (10): 973-980.

Global Market Insights (2014). Gold nanoparticles market size by application (electronics, medical & dentistry, catalysis), industry analysis report, regional outlook, application potential, price trend, competitive market share & forecast, 2015-2022. https://www.gminsights.com/industry-analysis/gold-nanoparticles-market (Accessed on 15 March, 2020).

Global Market Insights (2018). Silver nanoparticles market size by application (healthcare & life sciences, textiles, electronics & IT, food & beverage), industry analysis report, regional outlook, growth potential, price trends, competitive market share & forecast, 2018–2024. https://www.gminsights.com/industry-analysis/silver-nanoparticles-market (Accessed on 15 March, 2020).

Golinska, P., Wypij, M., Ingle, A.P., Gupta, I., Dahm, H., and Rai, M. (2014). Biogenic synthesis of metal nanoparticles from actinomycetes: biomedical

applications and cytotoxicity. *Applied Microbiology and Biotechnology* **98** (19): 8083-8097.

Grand View Research (2019). Graphene market size, share & trends analysis report by application (electronics, composites, energy), by product (graphene nanoplatelets, graphene oxide), by region, and segment forecasts, 2019 – 2025. https://www.grandviewresearch.com/industry-analysis/graphene-industry (Accessed on 15 March, 2020).

Gueguim-Kana, E.B., Oloke, J.K., and **Lateef, A**. (2001). Overproduction of ammonia by a local isolate of *Staphylococcus aureus* in a cheaply fabricated medium. *NISEB Journal* **1** (4): 297-304.

Gueguim-Kana, E.B., Oloke, J.K., and **Lateef, A**. (2003a). Construction of a rugged 4.5 litre bioreactor for the fermentation of *Actinomyces* sp. *African Scientist* **4** (1): 1-5.

Gueguim-Kana, E.B., Oloke, J.K., and **Lateef, A**. (2007b). Novel feeding strategies for *Saccharomyces cerevisiae* DS2155, using glucose limited exponential fed batch cultures with variable specific growth rates (μ). *African Journal of Biotechnology* **6** (9): 1122-1127.

Gueguim-Kana, E.B., Oloke, J.K., and **Lateef, A**. (2007c). Advanced control of fermentation processes. *Journal of Science Research* **7** (1): 54-59.

Gueguim-Kana, E.B., Oloke, J.K., **Lateef, A**., and Adesiyan M.O. (2012a). Modeling and optimization of biogas production on saw dust and other co-substrates using Artificial Neural Network and Genetic Algorithm. *Renewable Energy* **46**: 276-281.

Gueguim-Kana, E.B., Oloke, J.K., **Lateef, A**., and Donfack-Kana, A.F. (2010b). Pro-optimizer: A novel web enabled optimization engine for microbial fermentations. *Biotechnology and Biotechnological Equipment* **24** (4): 2137-2141.

Gueguim-Kana, E.B., Oloke, J.K., **Lateef, A**., and Oyebanji, A. (2012b). Comparative evaluation of artificial neural network coupled genetic algorithm and response surface methodology for modelling and optimization of citric acid production by *Aspergillus niger* MCBN 297. *Chemical Engineering Transactions* **27**: 397-402.

Gueguim-Kana, E.B., Oloke, J.K., **Lateef, A**., and Zebaze Kana, M.G. (2005). Trends in microbial fermentation processes using Artificial Intelligence tools. In: *Genetic Resources and Biotechnology*, Volume 2. Eds: Thangadurai, D., Pullaiah, T., and Ballati, A Pedro. Regency Publications, New Delhi, India. ISSN 81-89233-15-7. Pp 131-142.

Gueguim-Kana, E.B., Oloke, J.K., **Lateef, A**., and Zebaze-Kana, M.G. (2007a). Novel optimal temperature profile for acidification process of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* in yoghurt fermentation using Artificial Neural Network and Genetic Algorithm. *Journal of Industrial Microbiology and Biotechnology* **34** (7): 491-496.

Gueguim-Kana, E.B., Oloke, J.K., **Lateef, A**., and Zebaze-Kana, M.G. (2003b). Constructional features of a home-made 15-litre bioreactor for fed-batch fermentations. *African Journal of Biotechnology* **2** (8): 233-236.

Gueguim-Kana, E.B., Oloke, J.K., **Lateef, A**., and Zebaze-Kana, M.G. (2003d). Use of artificial intelligence in control and optimization of microbial fermentations. *Science Focus* **3**: 56-60.

Gueguim-Kana, E.B., Oloke, J.K., **Lateef, A**., Azanfack Kenfack, A.H., and Adeyemi, A. (2010a). Implementation details of computerized Temporary Immersion Bioreactor (TIB): A fermentation case of *Pleurotus pulmonarius*. *Biotechnology and Biotechnological Equipment* **24** (4): 2149-2153.

Gueguim-Kana, E.B., Oloke, J.K., Zebaze-Kana, M.G., and **Lateef, A**. (2003c). Computer software for real time control and monitoring of fermentation processes. *Asian Journal of Microbiology, Biotechnology and Environmental Sciences* **5** (4): 415-419.

Hatami, H. (2013). Importance of water and water-borne diseases: on the occasion of the world water day (March 22, 2013). *International Journal of Preventive Medicine* **4** (3): 243-245.

Hulla, J.E., Sahu, S.C., and Hayes, A.W. (2015). Nanotechnology: History and future. *Human and Experimental Toxicology* **34** (12): 1318-1321.

IITA (2019). Major breakthrough for farmers and scientists as Nigerian biotech body approves commercial release of genetically modified cowpea. https://www.iita.org/news-item/major-breakthrough-for-farmers-and-scientists-as-nigerian-biotech-body-approves-commercial-release-of-genetically-modified-cowpea/ (Accessed on 8 March, 2020).

ISI Web of Knowledge Data (2019). https://statnano.com/report/s88 (Accessed on 13 October, 2019).

Isolauri, E., Salminen, S., and Ouwehand, A.C. (2004). Probiotics. *Best Practice and Research Clinical Gastroenterology* **18** (2): 299-313.

Jahan, N., Shahid, F., Aman, A., Mujahid, T.Y., and Qader, S.A.U. (2017). Utilization of agro waste pectin for the production of industrially important polygalacturonase. *Heliyon* **3** (6): e00330. https://doi.org/10.1016/j.heliyon.2017.e00330.

Ji, C., Nguyen, L.N., Hou, J., Hai, F.I., and Chen, V. (2017). Direct immobilization of laccase on titania nanoparticles from crude enzyme extracts of *P. ostreatus* culture for micro-pollutant degradation. *Separation and Purification Technology* **178**: 215-223.

Kerry, R.G., Gouda, S., Sil, B., Das, G., Shin, H.S., Ghodake, G., and Patra, J.K. (2018). Cure of tuberculosis using nanotechnology: An overview. *Journal of Microbiology* **56** (5): 287-299.

Khanday, M.F. (2018). Convergence of nanotechnology and microbiology. In *Biomedical Engineering: Concepts, Methodologies, Tools, and Applications*. IGI Global, Hershey, USA. Pp. 1-22. https://doi.org/10.4018/978-1-5225-3158-6.ch001.

Khanvilkar, S.S., and Arya, S.S. (2015). Fructooligosaccharides: applications and health benefits. *Agro Food Industry Hi Tech* **26** (6): 8-12.

Kilbourne, E.D. (2006). Influenza pandemics of the 20th century. *Emerging Infectious Diseases* **12**(1): 9-14.

Kržanović, D., Conić, V., Bugarin, D., Jovanović, I., and Božić, D. (2019). Maximizing economic performance in the mining industry by applying bioleaching technology for extraction of

polymetallic mineral deposits. *Minerals* **9** (7): 400. https://doi.org/10.3390/min9070400.

Lane, N. (2015). The unseen world: reflections on Leeuwenhoek (1677) 'Concerning little animals'. *Philosophical Transactions of the Royal Society B: Biological Sciences* **370** (1666): 20140344.

Lateef, A. (2001). The use of a hyper-ammonia producing strain of *Pseudomonas aeruginosa* in the formulation of ammonia-based biofertilizer. Unpublished M.Tech Dissertation, Department of Pure and Applied Biology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. Pp. 78.

Lateef, A. (2004). The microbiology of a pharmaceutical effluent and its public health implications. *World Journal of Microbiology and Biotechnology* **20** (2): 167-171.

Lateef, A. (2005a). Microbial production of fructooligosaccharides by *Aureobasidium pullulans* CFR 77. Unpublished CSIR/TWAS Postgraduate Fellowship Report, Department of Fermentation Technology and Bioengineering, Central Food Technological Research Institute (CFTRI), Mysore, India. Pp. 77.

Lateef, A. (2005b). Comparative study of the efficiency of oligosaccharide production by α-amylase, β-galactosidase and fructofuranosidase from selected microorganisms. Unpublished PhD Thesis, Department of Pure and Applied Biology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. Pp. 178.

Lateef, A. (2020a). Nanotechnology in the Eyes of Life Scientists: Personal Experiences. Being a paper delivered at the International webinar organized by the Department of Zoology, PSGR Krishnammal College for Women, Bharathiar University, Coimbatore, India on 13 October, 2020. https://doi.org/10.13140/RG.2.2.35344.64007.

Lateef, A. (2020b). Applications of nanoparticles: perspectives from nanobiotechnology. Being a paper delivered at the International webinar organized by Post Graduate Department of Chemistry, and IQAC, TATA College, Chaibasa, India on 27 August, 2020. https://doi.org/10.13140/RG.2.2.21106.32966.

Lateef, A., Adelere, I.A., and Gueguim-Kana, E.B. (2015a). *Bacillus safensis* LAU 13: a new source of keratinase and its multi-functional biocatalytic applications. *Biotechnology and Biotechnological Equipment* **29** (1): 54-63.

Lateef, A., Adelere, I.A., and Gueguim-Kana, E.B. (2015b). The biology and potential biotechnological applications of *Bacillus safensis*. *Biologia* **70** (4): 411-419.

Lateef, A., Adelere, I.A., Gueguim-Kana, E.B., Asafa, T.B, and Beukes, L.S. (2015c). Green synthesis of silver nanoparticles using keratinase obtained from a strain of *Bacillus safensis* LAU 13. *International Nano Letters* **5** (1): 29-35.

Lateef, A., Akande, M.A., Azeez, M.A., Ojo, S.A., Folarin, B.I., Gueguim-Kana, E.B., and Beukes, L.S. (2016f). Phytosynthesis of silver nanoparticles (AgNPs) using miracle fruit plant (*Synsepalum dulcificum*) for antimicrobial, catalytic, anti-

coagulant and thrombolytic applications. *Nanotechnology Reviews* **5** (6): 507-520.

Lateef, A., Akande, M.A., Ojo, S.A., Folarin, B.I., Gueguim-Kana, E.B., and Beukes, L.S. (2016e). Paper wasp nest-mediated biosynthesis of silver nanoparticles for antimicrobial, catalytic, anti-coagulant and thrombolytic applications. *3Biotech*. **6**: 140. http://dx.doi.org/10.1007/s13205-016-0459-x.

Lateef, A., and Adeeyo, A.O. (2015). Green synthesis and antibacterial activities of silver nanoparticles using extracellular laccase of *Lentinus edodes. Notulae Scientia Biologicae* **7** (4): 405-411.

Lateef, A., and Araromi, D.O. (2002). Preliminary studies on the conversion of whey to Glycol by a strain of *Klebsiella* sp. *NISEB Journal* **2** (1): 11-15.

Lateef, A., and Araromi, D.O. (2003). Production of high-content fructooligosaccharides by an enzymatic system from osmophilic *Micrococcus* sp. *African Scientist* **4** (1): 7-12.

Lateef, A., and Gueguim-Kana, E.B. (2012). Utilization of cassava wastes in the production of fructosyltransferase by *Rhizopus stolonifer* LAU 07. *Romanian Biotechnological Letters* **17** (3): 7309-7316.

Lateef, A., and Gueguim-Kana, E.B. (2014). Quality assessment and hazard analysis in the small-scale production of poultry feeds in Ogbomoso, Southwest, Nigeria. *Quality Assurance and Safety of Crops and Foods* **6** (1): 105-113.

Lateef, A., and Ojo, M.O. (2016). Public health issues in the processing of cassava (*Manihot esculenta*) for the production of '*lafun'* and the application of

hazard analysis control measures. *Quality Assurance and Safety of Crops and Foods* **8** (1): 165-177.

Lateef, A., and Oloke, J.K. (2002). The effect of *Pseudomonas aeruginosa* ammonia-based biofertilizer on yield performance of two maize varieties in Green house. *Bioscience Research Communications* **14** (6): 521-528.

Lateef, A., and Oloke, J.K. (2003a). Enzymatic synthesis of oligosaccharides by *Actinomyces* sp. *Asian Journal of Microbiology, Biotechnology and Environmental Sciences* **5** (3): 291-295.

Lateef, A., and Oloke, J.K. (2003b). Resistance patterns of some clinical and soil isolates of *Pseudomonas aeruginosa. Science Focus* **4**: 22-26.

Lateef, A., and Oloke, J.K. (2005). Inhibitory effects of selected disinfectants and antiseptics on some resistant strains of *Pseudomonas aeruginosa. Global Journal of Pure and Applied Sciences* **11** (3): 367-369.

Lateef, A., and Yekeen, T.A. (2006). Microbial attributes of a pharmaceutical effluent and its genotoxicity on *Allium cepa. International Journal of Environmental Studies* **63** (5): 534-536.

Lateef, A., and Yusuf, W.A. (2002). Evaluation of the microbiological safety of some NAFDAC approved 'Pure water' in some Nigerian cities. *NISEB Journal* **2** (2): 119-121.

Lateef, A., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Akinboro, A., Oladipo, I.C., Azeez, L., Ajibade, S.E., Ojo, S.A., Gueguim-Kana, E.B., and Beukes, L.S. (2016c). Biogenic synthesis of silver nanoparticles using a pod extract of *Cola nitida*:

Antibacterial, antioxidant activities and application as a paint additive. *Journal of Taibah University for Science* **10** (4): 551-562.

Lateef, A., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Akinboro, A., Oladipo, I.C., Azeez, L., Ojo, S.A., Gueguim-Kana, E.B., and Beukes, L.S. (2016d). Cocoa pod extract-mediated biosynthesis of silver nanoparticles: Its antimicrobial, antioxidant and larvicidal activities. *Journal of Nanostructure in Chemistry* **6** (2): 159-169.

Lateef, A., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Akinboro, A., Oladipo, I.C., Ajetomobi, F.E., Gueguim-Kana, E.B., and Beukes, L.S. (2015d). *Cola nitida*-mediated biogenic synthesis of silver nanoparticles using seed and seed shell extracts and evaluation of antibacterial activities. *BioNanoScience* **5** (4): 196-205.

Lateef, A., Darwesh, O.M., and Matter, I.A**.** (2021b). Microbial Nanobiotechnology: The Melting Pot of Microbiology, Microbial Technology and Nanotechnology. In: Lateef, A., Gueguim-Kana, E.B., Dasgupta, N., and Ranjan, S. (Eds.). *Microbial Nanobiotechnology: Principles and Applications.* Springer Nature Singapore Pte. Ltd. ISBN 978-981-334-777-9. https://doi.org/10.1007/978-981-33-4777-9_1**.** Pp. 1-19.

Lateef, A., Davies, T.E., Adelekan, A., Adelere, I.A., Adedeji, A.A., and Fadahunsi, A.H. (2010a). *Akara* Ogbomoso: microbiological examination and identification of hazards and critical control points. *Food Science and Technology International* **16** (5): 389-400.

Lateef, A., Elegbede, J.A., Akinola, P.O., and Ajayi, V.A. (2019). Biomedical applications of green synthesized-metallic nanoparticles: a review. *Pan African Journal of Life Sciences* **3**: 157-182.

Lateef, A., Folarin, B.I., Oladejo, S.M., Akinola, P.O., Beukes, L.S., and Gueguim-Kana, E.B. (2018a). Characterization, antimicrobial, antioxidant and anticoagulant activities of silver nanoparticles synthesized from *Petiveria alliacea* L. leaf extract. *Preparative Biochemistry and Biotechnology* **48** (7): 646-652.

Lateef, A., Gueguim-Kana, E.B., Dasgupta, N., and Ranjan, S. (2021a). *Microbial Nanobiotechnology: Principles and Applications.* Springer Nature Singapore Pte. Ltd. ISBN 978-981-334-777-9. 588p. https://doi.org/10.1007/978-981-33-4777-9.

Lateef, A., Kolawole, L.L., and Agosu, O.S. (2012a). Quality Assessment of some Groundwater Samples in *Ogbomoso* metropolis, Southwest Nigeria. *Journal of Environment and Earth Science* **2** (6): 39-47.

Lateef, A., Ogunkunle, A.T.J., and Adigun, G.O (2016i). Google scholar citation in retrospect: visibility and contributions of African scholars. *COLLNET Journal of Scientometrics and Information Management* **10** (2): 219-236.

Lateef, A., Ojo, S.A., Akinwale, A.S., Azeez, L., Gueguim-Kana, E.B., and Beukes, L.S. (2015e). Biogenic synthesis of silver nanoparticles using cell-free extract of *Bacillus safensis* LAU 13: antimicrobial, free radical scavenging and larvicidal activities. *Biologia* **70** (10): 1295-1306.

Lateef, A., Ojo, S.A., and Elegbede, J.A. (2016a). The emerging roles of arthropods and their metabolites in the green synthesis of metallic nanoparticles. *Nanotechnology Reviews* **5** (6): 601-622.

Lateef, A., Ojo, S.A., and Oladejo, S.M. (2016g). Anti-candida, anti-coagulant and thrombolytic activities of biosynthesized silver nanoparticles using cell-free extract of *Bacillus safensis* LAU 13. *Process Biochemistry* **51** (10): 1406-1412.

Lateef, A., Ojo, S.A., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Akinboro, A., Oladipo, I.C., Gueguim-Kana, E.B., and Beukes, L.S. (2016b). Cobweb as novel biomaterial for the green and eco-friendly synthesis of silver nanoparticles. *Applied Nanoscience* **6** (6): 863-874.

Lateef, A., Ojo, S.A., Elegbede, J.A., Akinola, P.O., and Akanni, E.O (2018b). Nanomedical applications of nanoparticles for blood coagulation disorders. In: Dasgupta, N., Ranjan, S., and Lichtfouse, E. (Eds.). *Environmental Nanotechnology.* Environmental Chemistry for a Sustainable World, Volume 14. https://doi.org/10.1007/978-3-319-76090-2_8. Springer International Publishing AG, Cham, Switzerland. ISBN 978-3-319-76089-6. Pp. 243-277.

Lateef, A., Ojo, S.A., Elegbede, J.A., Azeez, M.A., Yekeen, T.A., and Akinboro, A. (2017). Evaluation of some biosynthesized silver nanoparticles for biomedical applications: hydrogen peroxide scavenging, anticoagulant and thrombolytic activities. *Journal of Cluster Science* **28** (3): 1379-1392.

Lateef, A., Ojo, S.A., Folarin, B.I., Gueguim-Kana, E.B., and Beukes, L.S. (2016h). Kolanut (*Cola nitida*) mediated synthesis of silver-gold alloy nanoparticles: antifungal, catalytic, larvicidal and thrombolytic applications. *Journal of Cluster Science* **27** (5): 1561-1577.

Lateef, A., Oloke, J.K., and Gueguim-Kana, E.B. (2003a). Overproduction of ammonia by a local isolate of *Pseudomonas aeruginosa* in cheaply fabricated media. *Research Communications in Microbiology* **1** (2): 62-67.

Lateef, A., Oloke, J.K., and Gueguim-Kana, E.B. (2003b). Production of oligosaccharides by partially purified α-amylase from *Alternaria alternata. Science Focus* **4**: 36-40.

Lateef, A., Oloke, J.K., and Gueguim-Kana, E.B. (2004a). Antimicrobial resistance of bacterial strains isolated from orange juice products. *African Journal of Biotechnology* **3** (6): 334-338.

Lateef, A., Oloke, J.K., and Gueguim-Kana, E.B. (2005). The Prevalence of bacterial resistance in clinical, food, water and some environmental samples in Southwest Nigeria. *Environmental Monitoring and Assessment* **100** (1-3): 59-69.

Lateef, A., Oloke, J.K., and Prapulla, S.G. (2007). Purification and partial characterization of intracellular fructosyltransferase from a novel strain of *Aureobasidium pullulans*. *Turkish Journal of Biology* **31** (3): 147-154.

Lateef, A., Oloke, J.K., and Prapulla, S.G. (2007a). The effect of ultrasonication on the release of fructosyltransferase from *Aureobasidium pullulans*

CFR 77. *Enzyme and Microbial Technology* **40**: 1067-1070.

Lateef, A., Oloke, J.K., Gueguim-Kana, E.B., and Adebayo, I. (2004b). Aspects of the isolation and characterization of thermostable α-amylase from *Alternaria alternata*. *Global Journal of Pure and Applied Sciences* **10** (1): 75-79.

Lateef, A., Oloke, J.K., Gueguim-Kana, E.B., and Pacheco, A.E. (2006). The microbiological quality of ice used to cool drinks and foods in Ogbomoso metropolis, Southwest, Nigeria. *Internet Journal of Food Safety* **8**: 39-43.

Lateef, A., Oloke, J.K., Gueguim-Kana, E.B., and Raimi, O.R. (2012b). Production of fructosyltransferase by a local isolate of *Aspergillus niger* in both submerged and solid substrate media. *Acta Alimentaria* **41** (1): 100-117.

Lateef, A., Oloke, J.K., Gueguim-Kana, E.B., Oyeniyi, S.O., Onifade, O.R., Oyeleye, A.O., Oladosu, O.C., and Oyelami A.O. (2008b). Improving the quality of agro-wastes by solid state fermentation: enhanced antioxidant activities and nutritional qualities. *World Journal of Microbiology and Biotechnology* **24** (10): 2369-2374.

Lateef, A., Oloke, J.K., Gueguim-Kana, E.B., Oyeniyi, S.O., Onifade, O.R., Oyeleye, A.O., and Oladosu, O.C. (2008a). *Rhizopus stolonifer* LAU 07: a novel source of fructosyltransferase. *Chemical Papers* **62** (6): 635-638.

Lateef, A., Oloke, J.K., Gueguim-Kana, E.B., Sobowale, B.O., Ajao, S.O., and Bello, B.Y. (2010b). Keratinolytic activities of a new feather-degrading isolate of *Bacillus cereus* LAU 08 isolated from

Nigerian soil. *International Bioremediation and Biodegradation* **64** (2): 162-165.

Lateef, A., Yekeen, T.A., and Ufuoma, P.E. (2007a). Bacteriology and genotoxicity of some pharmaceutical wastewaters in Nigeria. *International Journal of Environment and Health* **1** (4): 551-562.

Lateef, A., Oladejo, S.M., Akinola, P.O., Aina, D.A., Beukes, L.S., Folarin, B.I., and Gueguim-Kana E.B. (2020). Facile synthesis of silver nanoparticles using leaf extract of *Hyptis suaveolens* (L.) Poit for environmental and biomedical applications. *IOP Conference Series: Materials Science and Engineering* **805**: 012042. https://doi.org/10.1088/1757-899X/805/1/012042.

Leeuwenhoek, A.V. (1753). IV. Part of a letter from Mr. Antony van Leeuwenhoek, FRS concerning green weeds growing in water, and some animalcula found about them. *Philosophical Transactions of the Royal Society of London* **23** (283): 1304-1311.

Levingstone, T. J., Herbaj, S., Redmond, J., McCarthy, H.O., and Dunne, N.J. (2020). Calcium phosphate nanoparticles-based systems for RNAi delivery: Applications in bone tissue regeneration. *Nanomaterials* **10** (1): 146. https://doi.org/10.3390/nano10010146.

Lin, Y., Wang, X., Huang, X., Zhang, J., Xia, N., and Zhao, Q. (2017). Calcium phosphate nanoparticles as a new generation vaccine adjuvant. *Expert Review of Vaccines* **16** (9): 895-906.

Litchfield, J.H. (1983). Single-cell proteins. *Science* **219** (4585): 740-746.

Lu, S., Zhang, X., and Xue, Y. (2017). Application of calcium peroxide in water and soil treatment: a review. *Journal of Hazardous Materials* **337**: 163-177.

Lu, Y., Wu, K., Jiang, Y., Guo, Y., and Desneux, N. (2012). Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services. *Nature* **487** (7407): 362-365.

Maloy, S., and Schaechter, M. (2006). The era of microbiology: a golden phoenix. *International Microbiology* **9** (1): 1-7.

Mandal, D., Bolander, M. E., Mukhopadhyay, D., Sarkar, G., and Mukherjee, P. (2006). The use of microorganisms for the formation of metal nanoparticles and their application. *Applied Microbiology and Biotechnology* **69** (5): 485-492.

Mussatto, S.I., and Mancilha, I.M. (2007). Non-digestible oligosaccharides: a review. *Carbohydrate Polymers* **68** (3): 587-597.

Nanotechnology Now (2010). Bridging the nanodivide: African nanoscience and nanotechnology. http://www.nanotech-now.com/news.cgi?story_id=36306 (Accessed on 15 March, 2020).

Natan, M., and Banin, E. (2017). From Nano to Micro: using nanotechnology to combat microorganisms and their multidrug resistance. *FEMS Microbiology Reviews* **41** (3): 302-322.

National Insight (2018). 2nd LAUTECHNANO Conference Holds in October. http://nationalinsightnews.com/2nd-lautechnano-conference-holds-in-october/ (Accessed on 30 September, 2018).

Ng, V.W., Chan, J.M., Sardon, H., Ono, R.J., García, J.M., Yang, Y.Y., and Hedrick, J.L. (2014). Antimicrobial hydrogels: A new weapon in the arsenal against multidrug-resistant infections. *Advanced Drug Delivery Reviews* **78**: 46-62.

Nichols, G., Gillespie, I., and deLouvois, J. (2000). The microbiological quality of ice used to cool drinks and ready-to-eat from retail and catering premises in the United Kingdom. *Journal of Food Protection* **63**: 78-82.

Nigerian Standard for Drinking Water Quality NIS-554-2015 (2015). Standards Organization of Nigeria, Abuja, Nigeria, pp. 21. https://africacheck.org/wp-content/uploads/2018/06/Nigerian-Standard-for-Drinking-Water-Quality-NIS-554-2015.pdf (Accessed on 17 March, 2020).

NRF (2015). Overview of NRF funding opportunities, grants management and rating of researchers.https://www.nrf.ac.za/sites/default/files/documents/Overview%20of%20NRF%20Funding%20Opportunities,%20Grant%20Management,%20and%20the%20Rating%20... 0.pdf (Accessed on 15 March, 2020).

Ojo, S.A., **Lateef, A.**, Azeez, M.A., Oladejo, S.M., Akinwale, A.S., Asafa, T.B., Yekeen, T.A., Akinboro, A., Oladipo, I.C., Gueguim-Kana, E.B., and Beukes, L.S. (2016). Biomedical and catalytic applications of gold and silver-gold alloy nanoparticles biosynthesized using cell-free extract of *Bacillus safensis* LAU 13: antifungal, dye degradation, anti-coagulant and thrombolytic

activities. *IEEE Transactions on NanoBioscience* **15** (5): 433-442.

Ojoawo, S.O., **Lateef, A**., Oyeniran, F.A., Kupoluyi, O.T., Opatola, O.S., and Daramola, J. O (2017). Bioaccumulation of heavy metals in steel processing industrial effluents using *Bacillus safensis* LAU 13. *Journal of Environment and Biotechnology Research* **6** (1): 58-63.

Okafor, N. (2007). Modern Industrial Microbiology and Biotechnology. Science Publishers, Enfield, USA.

Olabemiwo, M.O., **Lateef, A**., Agunbiade, F.O., Akanji, S.B., and Bakare, H.O. (2020). The effects on oxidative aging, physical and flow properties of Agbabu natural bitumen modified with silver nanoparticles. *Heliyon* **6**: e04164.

Oladipo, I.C., **Lateef, A**., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Akinboro, A., Akinwale, A.S., Gueguim-Kana, E.B., and Beukes, L.S. (2017a). Green synthesis and antimicrobial activities of silver nanoparticles using cell-free extracts of *Enterococcus* species. *Notulae Scientia Biologicae* **9** (2): 196-203.

Oladipo, I.C., **Lateef, A**., Elegbede, J.A., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Akinboro, A., Gueguim-Kana, E.B., Beukes, L.S., Oluyide, T.O., and Atanda, O.R. (2017b). *Enterococcus* species for the one-pot biofabrication of gold nanoparticles: characterization and nanobiotechnological applications. *Journal of Photochemistry and Photobiology B: Biology* **173**: 250-257.

Oladipo, I.C., **Lateef, A**., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Ogunsona, S.B., Irshad, H.M., and Abbas, S.H. (2020b). Characterization

and biomedical application of phytosynthesized gold nanoparticles from *Datura stramonium* seed extract. *IOP Conference Series: Materials Science and Engineering* **805**: 012021. https://doi.org/10.1088/1757-899X/805/1/012021.

Oladipo, I.C., **Lateef, A**., Azeez, M.A., Asafa, T.B., Yekeen, T.A., Ogunsona, S.B., Irshad, H.M., and Abbas, S.H. (2020a). Antidiabetic properties of phytosynthesized gold nanoparticles (AuNPs) from *Datura stramonium* seed. *IOP Conference Series: Materials Science and Engineering* **805**: 012035. https://doi.org/10.1088/1757-899X/805/1/012035.

Olajire, A.A., Abidemi, J.J., **Lateef, A**., and Benson, N.U. (2017). Adsorptive desulphurization of model oil by Ag nanoparticles-modified activated carbon prepared from brewer's spent grains. *Journal of Environmental Chemical Engineering* **5** (1): 147-159.

Orth, R.N., Foquet, M., Moran-Mirabal, J.M., Craighead, H., and Hajjar, D.P. (2016). Nanotechnology: Tools microbiologists can use to refine their research and become nanobiologists. In: *Cosmetic and Drug Microbiology*. CRC Press, Boca Raton, USA. Pp. 293-316. https://doi.org/10.3109/9781420019919-20.

Patra, J.K., Shin, H.S., and Paramithiotis, S. (2018). Application of nanotechnology in food science and food microbiology. *Frontiers in Microbiology* **9**: 714. https://doi.org/10.3389/fmicb.2018.00714.

Perelshtein, I., Lipovsky, A., Perkas, N., Tzanov, T., Arguirova, M., Leseva, M., and Gedanken, A. (2015). Making the hospital a safer place by

sonochemical coating of all its textiles with antibacterial nanoparticles. *Ultrasonics Sonochemistry* **25**: 82-88.

Pradeep, T. (2009). Noble metal nanoparticles for water purification: a critical review. *Thin Solid Films* **517** (24): 6441-6478.

Prapulla, S.G., Subhaprada, V., and Karanth, N.G. (2000). Microbial production of oligosaccharides: a review. *Advances in Applied Microbiology* **47**: 299-343.

Rahaman, M.M., and Varis, O. (2005). Integrated water resources management: evolution, prospects and future challenges. *Sustainability: Science, Practice and Policy* **1** (1): 15-21.

Rai, M., and Duran, N. (Eds.). (2011). *Metal Nanoparticles in Microbiology*. Springer-Verlag, Berlin, Germany. https://doi.org/10.1007/978-3-642-18312-6.

Raj, S., Jose, S., Sumod, U. S., and Sabitha, M. (2012). Nanotechnology in cosmetics: Opportunities and challenges. *Journal of Pharmacy and Bioallied Sciences* **4** (3): 186-193.

Ramlogan, R. (1997). Environment and human health: A threat to all. *Environmental Management and Health* **8** (2): 51-66.

Rani, K.Y., and Rao, V.R. (1999). Control of fermenters–a review. *Bioprocess Engineering* **21** (1): 77-88.

Rani, S.J., and Usha, R. (2013). Transgenic plants: Types, benefits, public concerns and future. *Journal of Pharmacy Research* **6** (8): 879-883.

Rather, I.A., Kim, B.C., Bajpai, V.K., and Park, Y.H. (2017). Self-medication and antibiotic resistance: Crisis, current challenges, and prevention. *Saudi Journal of Biological Sciences* **24** (4): 808-812.

Rawat, R.S. (2015). Dense plasma focus-from alternative fusion source to versatile high energy density plasma source for plasma nanotechnology. *Journal of Physics: Conference Series* **591**: 012021. https://doi.org/10.1088/1742-6596/591/1/012021.

Research and Markets (2018). Protein extracts from single cell protein sources market by source-global market size, share, development, growth and demand forecast, 2013-2023. https://www.researchandmarkets.com/reports/4655419/protein-extracts-from-single-cell-protein-sources (Accessed on 4 March, 2020).

Ritala, A., Häkkinen, S.T., Toivari, M., and Wiebe, M.G. (2017). Single cell protein—state-of-the-art, industrial landscape and patents 2001-2016. *Frontiers in Microbiology* **8**: 2009. https://doi.org/10.3389/fmicb.2017.02009.

Rolf, M.J., and Lim, H.C. (1982). Computer control of fermentation processes. *Enzyme and Microbial Technology* **4** (6): 370-380.

Sangeetha, P. T., Ramesh, M.N., and Prapulla, S.G. (2005). Recent trends in the microbial production, analysis and application of fructooligosaccharides. *Trends in Food Science and Technology* **16** (10): 442-457.

Sanusi, I.A., Faloye, F.D., and Kana, E.G. (2019). Impact of various metallic oxide nanoparticles on ethanol production by *Saccharomyces cerevisiae* BY4743: screening, kinetic study and validation on potato waste. *Catalysis Letters* **149** (7): 2015-2031.

Sanusi, I.A., Suinyuy, T.N., **Lateef, A**., and Gueguim-Kana E.B. (2020). Effect of nickel oxide nanoparticles on bioethanol production: Process optimization, kinetic

and metabolic studies. *Process Biochemistry* **92**: 386-400.

Satomi, M., Myron, T., Duc, L., and Venkateswaran K. (2006). *Bacillus safensis* sp. nov., isolated from spacecraft and assembly facility surfaces. *International Journal of Systematic and Evolutionary Microbiology* **56**: 1735-1740.

Schmidt, M., Babu, K., Khanna, N., Marten, S., and Rinas, U. (1999). Temperature-induced production of recombinant human insulin in high-cell density cultures of recombinant *Escherichia coli*. *Journal of Biotechnology* **68** (1): 71-83.

Schuster, E., Dunn-Coleman, N., Frisvad, J.C., and Van Dijck, P.W. (2002). On the safety of *Aspergillus niger*–a review. *Applied Microbiology and Biotechnology* **59** (4-5): 426-435.

SciDev.Net (2017). Nanotech holds promise for Africa, but not prioritized. https://www.scidev.net/sub-saharan-africa/r-d/news/nanotech-africa-prioritised.html (Accessed on 18 October, 2017).

Sekoai, P.T., Ouma, C.N.M., Du Preez, S.P., Modisha, P., Engelbrecht, N., Bessarabov, D.G., and Ghimire, A. (2019). Application of nanoparticles in biofuels: an overview. *Fuel* **237**: 380-397.

Sewsynker, Y., Gueguim-Kana, E.B., and **Lateef, A**. (2015). Modelling of biohydrogen generation in microbial electrolysis cells (MECs) using a committee of artificial neural networks (ANNs). *Biotechnology and Biotechnological Equipment* **29** (6): 1208-1215.

Sharma, A., Sharma, S., Sharma, K., Chetri, S.P., Vashishtha, A., Singh, P., Kumar, R., Rathi, B., and Agrawal, V. (2016). Algae as crucial organisms in

advancing nanotechnology: a systematic review. *Journal of Applied Phycology* **28** (3): 1759-1774.

Sharma, D., Kanchi, S., and Bisetty, K. (2019). Biogenic synthesis of nanoparticles: A review. *Arabian Journal of Chemistry* **12** (8): 3576-3600.

Show, P.L., Oladele, K.O., Siew, Q.Y., Zakry, F.A., Lan, J.C.W., and Ling, T.C. (2015). Overview of citric acid production from *Aspergillus niger*. *Frontiers in Life Science* **8** (3): 271-283.

Singh, P., Kim, Y.J., Zhang, D., and Yang, D.C. (2016). Biological synthesis of nanoparticles from plants and microorganisms. *Trends in Biotechnology* **34** (7): 588-599.

STAT NANO (2020a). Nanotechnology patents in USPTO (Patent). https://statnano.com/report/s103 (Accessed on 15 March, 2020).

STAT NANO (2020b). Nigeria. https://statnano.com/country/nigeria (Accessed on 15 March, 2020).

STAT NANO (2020c). South Africa. https://statnano.com/country/south-africa(Accessed on 15 March, 2020).

Steinkraus, K.H. (2002). Fermentations in world food processing. *Comprehensive Reviews in Food Science and Food Safety* **1** (1): 23-32.

Taniguchi, N. (1974). On the basic concept of nanotechnology. In *Proceedings of International Conference on Production Engineering, Tokyo, Part II,* 18-23.

The Business Day (2018a). Group calls for proper research funding in tertiary institutions. The Business Day, Lagos, Nigeria, Oct. 22, 2018; pg. A2.

The Business Day (2018b). Focus on product formation studies, science minister tells research institutes. The Business Day, Lagos, Nigeria, Nov. 6, 2018; pg. A1.

The Business Day (2019a). LAUTECH *NANO*$^{+}$ urges government to fund research into nanotechnology. The Business Day, Lagos, Nigeria, Oct. 6, 2019. https://businessday.ng/education/article/lautech-nano-urges-government-to-fund-research-into-nanotechnology/ (Accessed on 6 October, 2019).

The Business Day (2019b). Funding, power, political commitment obstacles to academic research in higher institution (2019). The Business Day, Lagos, Nigeria, Nov. 1, 2019. https://businessday.ng/education/article/funding-power-political-commitment-obstacles-to-academic-research-in-higher-institutions/ (Accessed on 2 November, 2019).

The Business Day (2019c). LAUTECH urges TETFund to prioritize funding nanotechnology research in Nigeria. The Business Day, Lagos, Nigeria, Nov. 17, 2019. https://businessday.ng/education/article/lautech-urges-tetfund-to-prioritize-funding-nanotechnology-research-in-nigeria/ (Accessed on 18 November, 2019).

The Daily Trust (2019). FG urged to hasten policy on nanotechnology. The Daily Trust, Media Trust Limited, Abuja, Nigeria, Nov. 18, 2019; pg. 27. https://www.dailytrust.com.ng/fg-urged-to-hasten-policy-on-nanotechnology.html (Accessed on 18 November, 2019).

The Guardian (2018a). Improved research funding critical to raising education standard – Researchers. The Guardian, Rutam House, Lagos, Nigeria, Oct. 21, 2018; pg. 5. https://guardian.ng/news/improved-research-funding-critical-to-raising-education-standard-researchers/ (Accessed on 21 October, 2018).

The Guardian (2018b). Minister urges increased research in nanotechnology. The Guardian, Rutam House, Lagos, Nigeria, Nov. 4, 2018; pg. 7. https://guardian.ng/technology/minister-urges-increased-research-in-nanotechnology/ (Accessed 4 November, 2018).

The Guardian (2019a). Scholars to appraise opportunities, constraints of nanotechnology. The Guardian, Rutam House, Lagos, Nigeria, Sept. 8, 2019; pg. 5. https://guardian.ng/news/scholars-to-appraise-opportunities-constraints-of-nanotechnology/ (Accessed on 9 September, 2019).

The Guardian (2019b). FG urged to fast-track passage, implementation of national policy on nanotechnology. The Guardian, Rutam House, Lagos, Nigeria, Nov. 17, 2019; pg. 6. https://guardian.ng/news/fg-urged-to-fast-track-passage-implementation-of-national-policy-on-nanotechnology/(Accessed on 17 November, 2019).

The Guardian (2020a). Nigeria needs roadmap for nanotechnology policy, development. The Guardian, Rutam House, Lagos, Nigeria, Oct. 18, 2020; pg. 6. https://guardian.ng/news/nigeria-needs-roadmap-for-nanotechnology-policy-development/ (Accessed on 18 October, 2020).

The Guardian (2020b). Nanotechnology is a veritable tool to achieving SDGS, say scholars**.** The Guardian, Rutam House, Lagos, Nigeria, Nov. 15, 2020; pg. 5. https://guardian.ng/news/nanotechnology-is-a-veritable-tool-to-achieving-sdgs-say-scholars/ (Accessed on 15 November, 2020).

The Nation (2019). LAUTECH VC wants special funding for nanotechnology research. The Nation, Vintage Press Limited, Lagos, Nigeria, Nov. 16, 2019; pg. 42. https://thenationonlineng.net/lautech-vc-wants-special-funding-for-nanotechnology-research/ (Accessed on 16 November, 2019).

The Nigerian Tribune (2017). LAUTECH hosts workshop on nanotechnology-Restates call for proper funding of varsities. The Nigerian Tribune, Tribune House, Ibadan, Nigeria, Aug. 17, 2017; pg. 19.

The Nigerian Tribune (2018). LAUTECH researchers underscore importance of Nanotechnology. The Nigerian Tribune, Tribune House, Ibadan, Nigeria, Nov. 1, 2018; pg. 21.

The Nigerian Tribune (2019). LAUTECH demands centre of excellence in nanotechnology. Nigerian Tribune, Tribune House, Ibadan, Nigeria, Nov 7, 2019. https://tribuneonlineng.com/lautech-demands-centre-of-excellence-in-nanotechnology/ (Accessed on 9 November, 2019).

The Nigerian Tribune (2019). What Nigeria will benefit from the commercialized GM cowpea. https://tribuneonlineng.com/what-nigeria-will-benefit-from-the-commercialised-gm-cowpea/ (Accessed on 4 March, 2020).

The Nigerian Tribune (2020). Onu assures of FG commitment to nanotechnology research, development in Nigeria. Says ministry will support establishment of nano centre at LAUTECH. Nigerian Tribune, Tribune House, Ibadan, Nigeria, Nov. 6, 2020. https://tribuneonlineng.com/onu-assures-of-fg-commitment-to-nanotechnology-research-development-in-nigeria/ (Accessed on 6 November, 2020).

Ullmann, A. (2007). Pasteur-Koch: Distinctive ways of thinking about infectious diseases. *Microbe-American Society for Microbiology* **2** (8): 383-387.

UNDP (2020). Goal 6: Clean water and sanitation. https://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-6-clean-water-and-sanitation.html (Accessed on 18 March, 2020).

Uskoković, V., Tang, S., Nikolić, M.G., Marković, S., and Wu, V.M. (2019). Calcium phosphate nanoparticles as intrinsic inorganic antimicrobials: In search of the key particle property. *Biointerphases* **14** (3): 031001. https://doi.org/10.1116/1.5090396.

van Zuylen, J. (1981). The microscopes of Antoni van Leeuwenhoek. *Journal of Microscopy* **121** (3): 309-328.

Vaňková, K., Onderková, Z., Antošová, M., and Polakovič, M. (2008). Design and economics of industrial production of fructooligosaccharides. *Chemical Papers* **62** (4): 375. https://doi.org/10.2478/s11696-008-0034-y.

Voegele, J.W., Gill, R.P., Murray, M.A., Dlugos, D.F., and Shurtleff, C.I. (2008). Nanoparticle treated medical devices. *U.S. Patent Application No. 11/771, 361*.

Woolhouse, M., Waugh, C., Perry, M.R., and Nair, H. (2016). Global disease burden due to antibiotic resistance–state of the evidence. *Journal of Global Health* **6** (1): 010306. https://doi.org/10.7189/jogh.06.010306.

Yadav, A., Kon, K., Kratosova, G., Duran, N., Ingle, A.P., and Rai, M. (2015). Fungi as an efficient mycosystem for the synthesis of metal nanoparticles: progress and key aspects of research. *Biotechnology Letters* **37** (11): 2099-2120.

Yekeen, T.A., Azeez, M.A., Akinboro, A., **Lateef, A**., Asafa, T.B., Oladipo, I.C., Oladokun, S.O., and Ajibola, A.A (2017a). Safety evaluation of green synthesized C*ola nitida* pod, seed and seed shell extracts-mediated silver nanoparticles (AgNPs) using *Allium cepa* assay. *Journal of Taibah University for Science* **11** (6): 895-909.

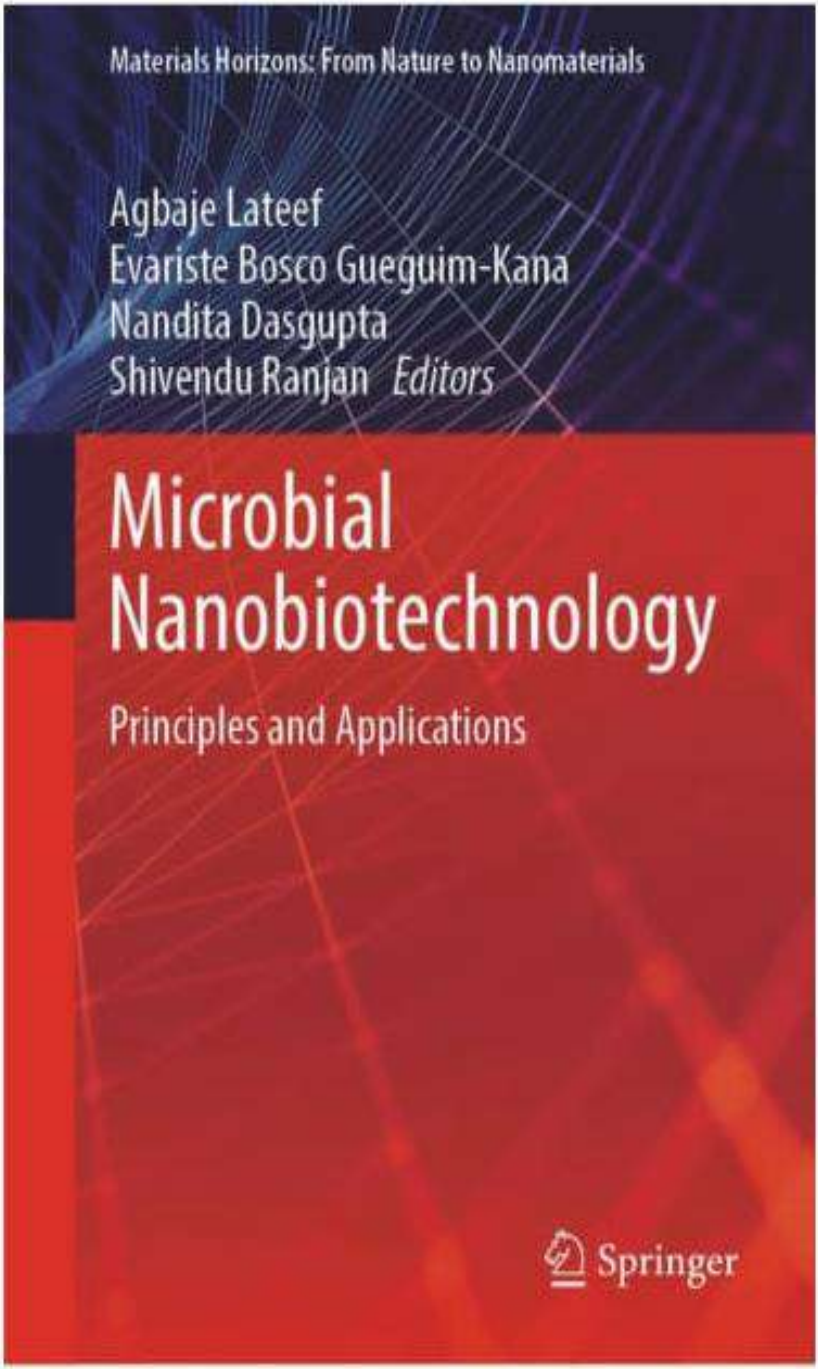
Yekeen, T.A., Azeez, M.A., **Lateef, A**., Asafa, T.B., Oladipo, I.C., Badmus, J.A., Adejumo, S.A., and Ajibola, A.A (2017). Cytogenotoxicity potentials of Cocoa pod and bean-mediated green synthesized silver nanoparticles on *Allium cepa* cells. *Caryologia: International Journal of Cytology, Cytosystematics and Cytogenetics* **70** (4): 366-377.

Yun, J. W. (1996). Fructooligosaccharides—occurrence, preparation, and application. *Enzyme and Microbial Technology* **19** (2): 107-117.

Zhang, X., Yan, S., Tyagi, R.D., and Surampalli, R.Y. (2011). Synthesis of nanoparticles by microorganisms and their application in enhancing microbiological reaction rates. *Chemosphere* **82** (4): 489-494.

Zhou, Y., Yuan, S., Liu, Q., Yan, D., Wang, Y., Gao, L., Han, J., and Shi, H. (2017). Synchronized purification and immobilization of his-tagged β-glucosidase via Fe_3O_4/PMG core/shell magnetic nanoparticles. *Scientific Reports* **7** (1): 1-11.

Zielińska-Górska, M.K., Sawosz, E., Górski, K., and Chwalibog, A. (2017). Does nanobiotechnology create new tools to combat microorganisms? *Nanotechnology Reviews* **6** (2): 171-189.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