FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA

ENZYMES: REDEFINING THE AXIOM 'JACK OF ALL TRADE'

BY:

Professor Egwim, Chidi Evans (FNSBMB)

(B.Sc Unilag, M.Sc and PhD Unilorin)

Professor of Industrial Biochemistry and Bio-process

INAUGURAL LECTURE
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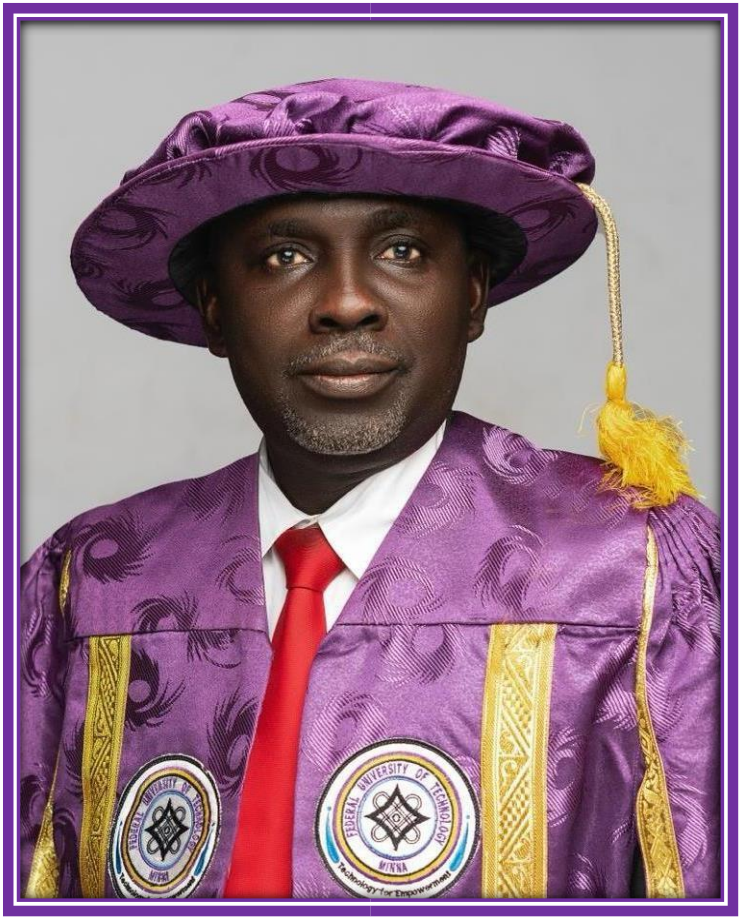

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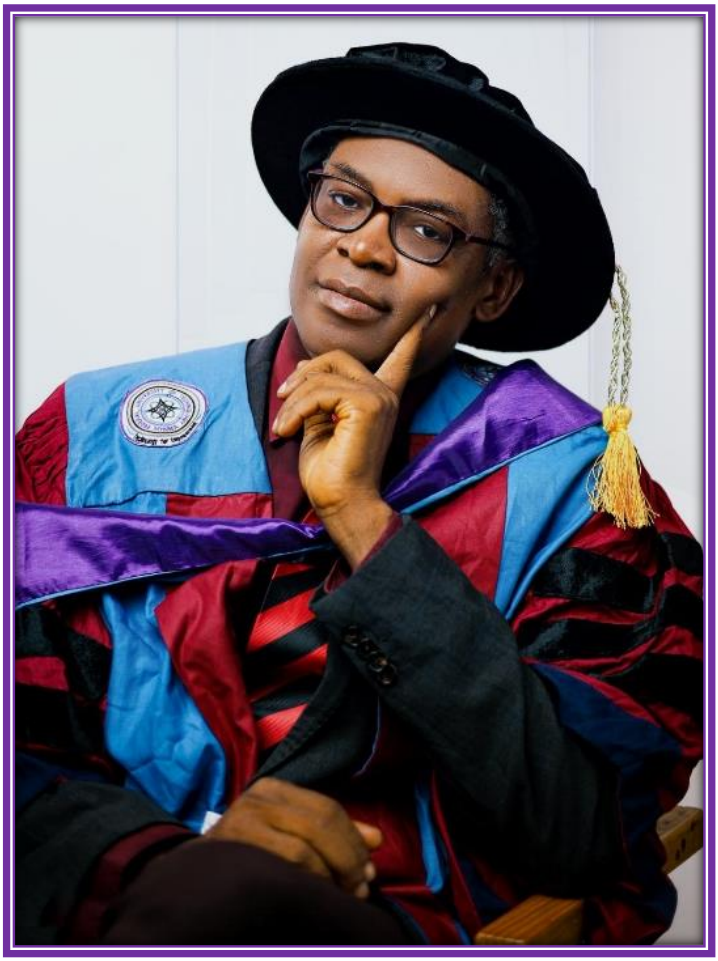

PROF. EGWIM, CHIDI EVANS

Protocol

Quotes

‘ Opportunities favors the curious mind’
Evans 1992

‘Its not bad to love, but who, how and why’
Evans 1999

Prologue

Enzymes, like true generalists, are the ultimate "jack of all trades" but also masters of many. Unlike the traditional notion that versatility comes at the cost of mastery, enzymes defy this axiom by driving all biological activities and finding applications across Life and Physical Sciences, Engineering, and Technology. Just as generalists leverage the 80/20 principle to achieve expertise efficiently, enzymes perform with remarkable specificity and efficiency in diverse functions. In a world dominated by specialization, enzymes prove that versatility and mastery can coexist, redefining the phrase “jack of all trades.”

1.0 Introduction

1.1 Enzymes

Enzymes, or biocatalysts, accelerate biochemical reactions in living organisms without being consumed. The term "enzyme" was introduced by Wilhelm Kühne in 1878, derived from the Greek words *en* (within) and *zume* (yeast), referencing yeast's role in alcohol fermentation. Enzymes consist of at least one polypeptide and can be proteins or glycoproteins. The protein component, called the apoenzyme, combines with a non-protein prosthetic group to form the holoenzyme. Catalysis occurs at the enzyme's active sites, which may contain essential groups linked by covalent or non-covalent interactions as shown in figure1.

Figure 1. A general equation for enzymatic reaction (1B) Schematic depicting the action of enzymes on the substrate.

1.1.1 Market size of industrial enzyme production

The industrial enzyme market is segmented by type (e.g., carbohydrases, proteases, lipases), application (e.g., food and beverages, animal feed, healthcare, textiles, detergents, biofuels), and region (covering 18 countries). Market sizing and forecasts are based on revenue (USD million), with the market valued at over USD 6,000 million in 2021 and projected to grow at a CAGR of more than 6% from 2022 to 2027. However, the COVID-19 pandemic disrupted growth due to lockdowns and supply chain disruptions affecting raw materials and enzyme production, impacting multiple end-user industries.

Carbohydrases dominated the market with over 45% revenue share in 2020, driven by demand from industries such as animal feed, food and beverages, and pharmaceuticals. The increasing use of pectinases and amylases in fruit juice processing for clarification and quality improvement is further fueling demand. Proteases, crucial for protein hydrolysis into amino acids, are widely used in animal feed, detergents, chemicals, food, pharmaceuticals, and even photography. The rapid expansion of pharmaceutical, detergent, and chemical industries in emerging markets like China, India, and Brazil is expected to further boost enzyme market growth in the coming years.

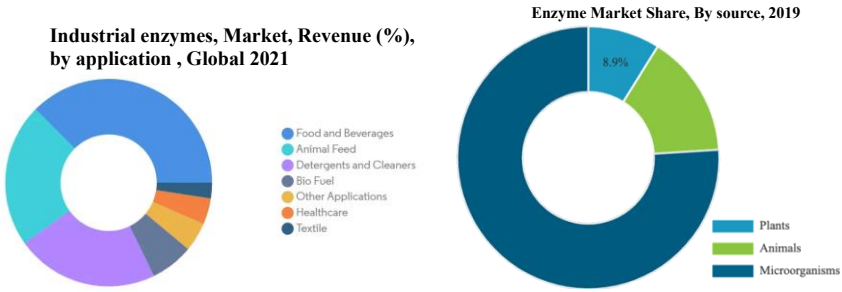

Figure 2. (A) The enzyme market share by source (2B) The industrial enzymes market revenue (%), Global 2021. The data is taken from "Enzymes Market Size, Share & Trends Analysis Report by Type (Industrial, Specialty), By Product (Carbohydrase, Proteases), By Source (Microorganisms, Animals), By Region, And Segment Forecasts, 2021 – 2028".

Table 1. Enzymes market report and Scope	
Report attributes	**Details**
Market size value in 2021	USD 11.47 billion
Revenue forecast in 2028	USD 17.88 billion
Growth rate	CAGR of 6.5% from 2021 to 2028
Regional scope	North America; Europe; Asia Pacific; Central & South America; Middle East & Africa
Product outlook	Carbohydrase, Proteases, Lipases, Polymerases, & Nucleases
Source outlook	Plants, Animals, Microorganisms
Key companies involved	BASF SE; Novozymes; DuPont Danisco; DSM; Novus International; Adisseo; Associated British Foods Plc; Chr. Hansen Holding A/S; Advanced Enzyme Technologies; Lesaffre; Enzyme Development Corporation

1.1.2 Process steps

Enzyme production has become a significant area in the modern biotechnology industry. Enzymes can be derived from different sources such as fungi, bacteria, yeasts, animals, and plants (Ayo *et al.*, 2021), however microbes act as an active source for unique biological enzymes and thus most enzymes are derived from microbial sources. Enzymes such as proteases have also been isolated from microbes obtained from waste dumpsites. In a study, lipase was extracted from crude oil contaminated soil isolates from six fungal strains (Elemuo *et al.*, 2019).

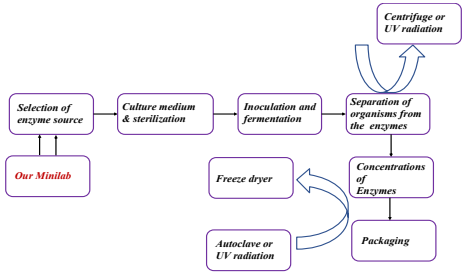

Figure 3. The process steps for different enzymes

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Figure 3. The process steps for different enzymes

Enzymes such as lipases, esterases, and proteases are obtained from plants and animals, with lysozyme primarily found in hen's eggs and human milk, while papaya and pineapple serve as sources of papain and bromelain. However, enzyme production from plants and animals faces challenges such as low yield, high costs, and inefficient isolation and purification processes. Microbial enzymes offer a more viable alternative due to their rapid growth, ease of cultivation, and cost-effectiveness. Various enzymes, including amylase, cellulase, glucose isomerase, and pectinase, are produced using microbes under controlled in vitro conditions (Emmanuel et al., 2020). The production process involves selecting microorganisms, preparing inoculum, sterilizing media, and optimizing fermentation conditions like pH, temperature, oxygen, and nutrient supplementation. Fermentation techniques such as batch and continuous sterilization ensure proper microbial growth, followed by enzyme recovery and purification. Extracellular enzymes are easier to extract, whereas intracellular enzymes require hydrolyzing agents and cell lysis, followed by differential centrifugation to separate cellular components. Further purification involves removing unwanted by-products and using chromatographic techniques for enzyme isolation (Bhatia, 2018).

2.0 Applications of Enzymes

Enzymes find application across various industries such as food and beverage, household care, animal feed, leather manufacturing, textile processing, pharmaceuticals, diagnostics, and therapeutics. Amylases, cellulases, and proteases are the most frequently used enzymes in the food, beverage, paper, and textile industries.

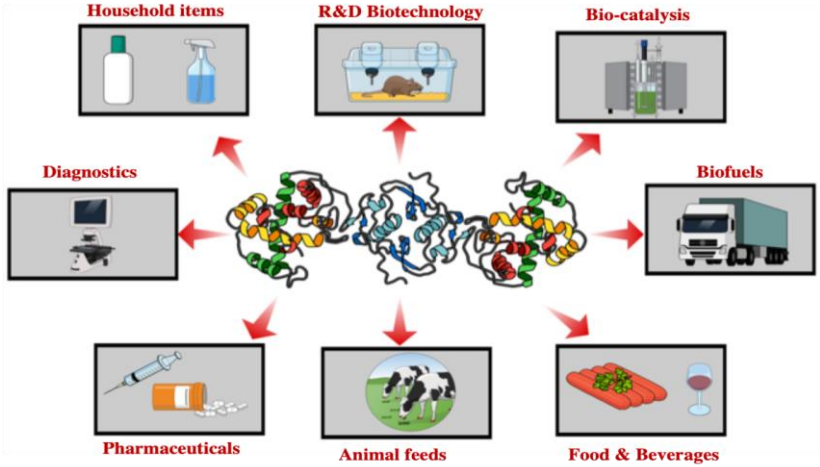

Fig 4. Schematics displaying the application of enzymes in various sectors.

2.1 *APPLICATION OF ENZYMES IN PHARMACEUTICALS*

Enzyme such as proteases, carbohydrases, and lipases have been widely utilized in the pharmaceutical and healthcare industries, with a growing market, particularly for proteases due to their benefits in immune system enhancement, prevention of inflammatory bowel diseases, and treatment of skin burns and stomach ulcers. Many pharmaceutical drugs and formulations use enzymes as active pharmaceutical ingredients (APIs), synthesized through microbial fermentation using bacteria like *Escherichia coli* and *Bacillus subtilis*, as well as fungi such as

Aspergillus oryzae, *Aspergillus niger*, *Trichoderma atroviride*, and yeasts like *Saccharomyces cerevisiae* and *Pichia pastoris*. These microorganisms, generally recognized as safe (GRAS), undergo submerged fermentation (SmF) and solid-state fermentation (SSF) for enzyme production. Enzymes are crucial for synthesizing antimicrobials like 6-amino penicillanic acid, utilizing penicillin acylase for economically viable enzyme-based production with immobilized enzymes, leading to cost savings in separation and reuse. Cephalosporin-derived antibiotics such as cefotaxime, ceftriaxone, cefuroxime, and cefdinir are also synthesized enzymatically. Additionally, essential amino acids like L-methionine, L-aspartic acid, and L-cysteine are produced using microbial enzymes, enhancing efficiency in amino acid synthesis (Meghwanshi et al., 2018).

Beyond drug synthesis, enzymes play a vital role in disease treatment by aiding digestion, detoxification, immune system strengthening, and metabolic regulation. They have been used to treat pancreatic insufficiency, cystic fibrosis, metabolic disorders, lactose intolerance, and cancer. Adenosine deaminase, crucial for purine metabolism and immune development, is employed in treating Severe Combined Immunodeficiency Disease (SCID), while glucocerebrosidase is used in enzyme replacement therapy for Gaucher's disease (Fenton et al., 2010). Enzymes like sacrosidase are applied in treating congenital sucrase-isomaltase deficiency (CSID), while proteolytic enzymes, such as those from pineapples, aid in burn wound treatment. Lysozyme has demonstrated antiviral activity against HIV, and chitinases are used as antimicrobials. Lytic bacteriophage-derived enzymes have shown efficacy against *Streptococcus pneumoniae*, *Clostridium perfringens,* and *Bacillus anthracis*. Enzymes also hold promise for cancer treatment, with PEG-immobilized arginine deaminase effective against hepatocellular carcinomas and skin cancers, while

PEGylated Oncaspar (pegaspargase) is used for leukemia and lymphoma therapy. Additionally, peptides from Nigerian leech have shown anticancer effects against human breast cancer cells (Ensor et al., 2002; Mgbemena et al., 2020)

2.1.1 EVALUATION OF CARBONIC ANHYDRASE AND LACTATE DEHYDROGENASE ACTIVITIES IN SELECTED CANCER PATIENTS ATTENDING NATIONAL HOSPITAL ABUJA

In a study by our team of researchers, it was established that breast cancer is the most common cancer type while the age range was from 25-75 years. The patients' characteristics indicated that previous family history of cancer was a risk factor. The carbonic anhydrase activity was significantly higher ($P \leq 0.05$) in prostate and breast cancer compared to the healthy control. Serum Lactate dehydrogenase was significantly increased ($P \leq 0.05$) in breast, prostate, osteosarcoma, colorectal, nasopharyngeal and neck cancer compared to the healthy control.

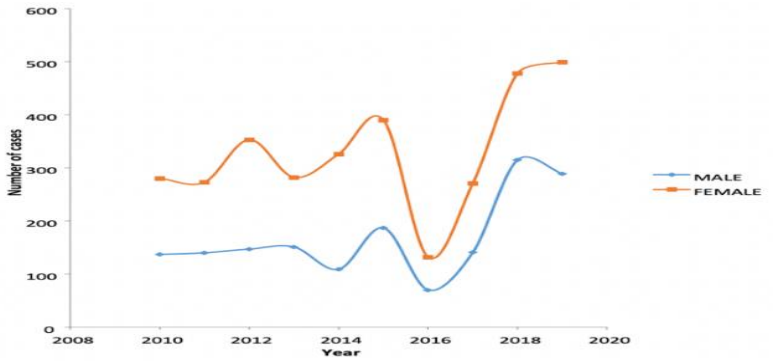

Figure 5. (A) Cancer Incidence in Male and Female Patients Attending National Hospital Abuja from 2010- 2019

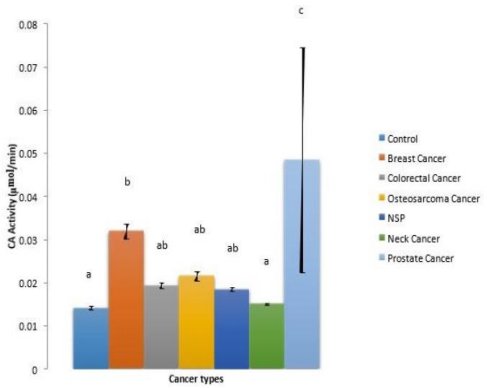

Figure 5. (B) Carbonic Anhydrase (CA) Activity in Different Cancer Types Among Patients Attending National Hospital Abuja

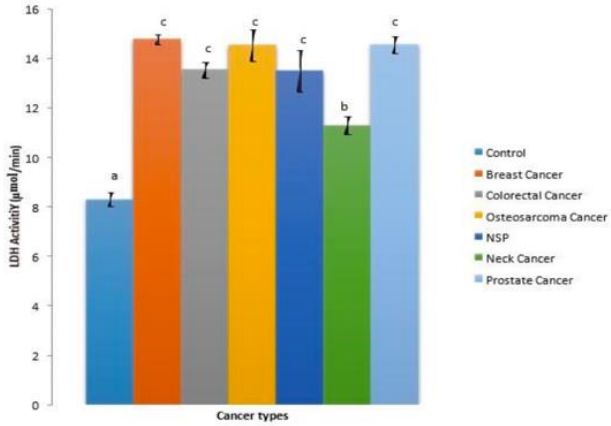

Figure 5. (C) Lactate Dehydrogenase (LDH) Activity in Different Cancer Types Among Patients Attending National Hospital Abuja

Awoniran and Egwim (2021)

2.1.1 APPLICATIONS OF ENZYMES IN FOOD INDUSTRY

Proteases are widely used in the food industry in processing fish and meat wastes. The use of alkaline proteinase from *Bacillus subtilis* in the processing of waste feathers from poultry slaughterhouses has been reported (Dalev 1994). Feathers constitute 5% of the body weight of poultry and can be considered as a high protein source for food and feed provided their rigid keratin structure is completely destroyed. Total solubilization of the feathers was achieved after pretreatment with NaOH, mechanical disintegration and enzyme hydrolysis. The end product was a heavy, grayish powder with a very high protein content which could be used mainly as feed constituent.

Other areas of applications in food processing

Different enzymes have found applications if different food industries

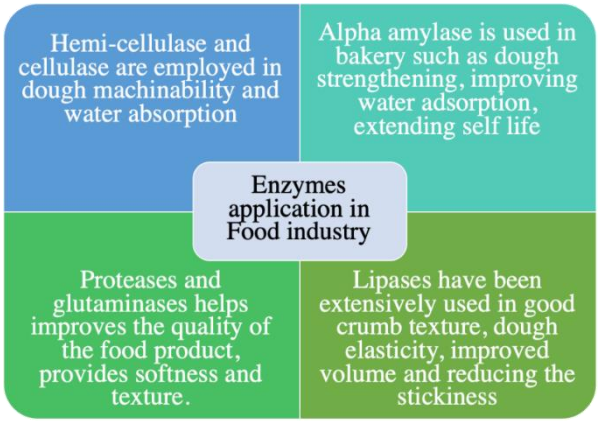

Table size broilers in 56 days Ayanwale et al., 2023

Figure 6. The schematics depicting the application of enzymes in food industry.

Catalase (EC 1.11.1.6) is an antioxidant enzyme that catalyzes the decomposition of hydrogen peroxide into water and oxygen. It is classified into monofunctional catalase, catalase-peroxidase, and pseudocatalase (Mn-catalase). Catalase is widely used in industrial applications, particularly in the food industry. In cheese production, hydrogen peroxide is employed as an alternative to pasteurization at high temperatures, preserving natural milk enzymes for flavor development, especially in Swiss cheese. However, residual H_2O_2 can interfere with bacterial cultures necessary for cheese fermentation, necessitating its removal using catalase. The U.S. Food and Drug Administration (FDA) permits this process, ensuring effective cold pasteurization. Additionally, complex enzyme preparations containing catalase have been found to enhance pasta and baked goods by improving texture, elasticity, and softness. The combination of catalase with glucose oxidase, L-ascorbic acid, or alginic acid propylene glycol ester has been shown to increase the quality of bread and baked products. Furthermore, food wrappers treated with catalase prevent oxidation, thereby extending shelf life.

Another significant application of catalase is in the baking industry, where it aids in glucose removal from egg whites before drying. A mixture of glucose oxidase and catalase, often with added hydrogen peroxide, ensures complete oxidation of glucose, preventing unwanted reactions in food products. Additionally, catalase is used in the beverage industry to remove oxygen from bottled and canned drinks, thereby preventing oxidation. In winemaking and mayonnaise production, catalase helps reduce non-enzymatic browning. The enzyme is also known for its free radical scavenging ability when coupled with

oxidase, which prevents oxidative damage responsible for food deterioration. These diverse applications underscore the enzyme's essential role in food preservation and processing (Lončar & Fraaije 2015).

2.1.2 EFFECT OF PECTINASE ON THE YIELD OF JUICE AND WINE FROM BANANA AND PAWPAW

• **Production of Pectinase Enzyme**: Pectinase has a tremendous industrial application especially, in food industry, for extraction and clarification of both sparkling clear juice (apple, pear, grapes and wine) and cloudy (lemon, orange, pineapple and mango) juice and maceration of plant tissue. Despite the usefulness of pectinase, the enzyme is not produced at commercial quantities in Nigeria. However, in a study by our research group, snail guts isolates were screened to identify those which may become good candidates for industrial production of pectinase (Egwim & Caleb 2015). Snails are natural degrader of plants, it is expected that microorganisms inhabiting their gut should be efficient in hydrolysing plant components like pectin. The bacteria isolated from the gut of snail include *B. subtilis*, *streptococcus sp*, and *S. aureus* while fungal isolates were *A. niger*, *P. notatum*, *Trychophyton violacium* and *Torulopsis datilla*. All the bacteria and only two of the fungal isolates showed zone of clearance on pectin agar plates, thus indicating the ability of these organisms to produce pectinase. From the bacteria screened for pectinase production, *Bacillus subtilis* showed the highest enzymatic activity. Pectinase has been produced locally for cheap content of our industries.

• **Effect of Pectinase:** In a study by our research group, carried out to investigate the potential and applicability of pectinase in

improving yield in the banana and paw-paw juice extraction process, it was discovered that pectinase has a positive effect on the slurry, residue, percentage yield, glucose and density (Egwim *et al.,* 2013). Increase in enzyme concentration leads to an increase in slurry volume, percentage yield, and glucose while it causes decrease in residue and density with a minimal effect on the pH. Following the application of commercial enzymes for the processing of juice and wine in the study, production of juice and wine by industries using pectinase and other enzymes is encouraged.

Figure 7. (A) Pawpaw juice (7B) Banana wine after two weeks of aging

2.1.3 PRETREATMENT AND HYDROLYSIS OF CASSAVA PEELS FOR FERMENTABLE SUGAR PRODUCTION

Fermentable sugars are important prerequisite for ethanol production. In a study by our research group, fermentable sugars were produced by pre-treatment and hydrolysis of cassava peels using *Aspergillus niger* and their crude enzymes (amylase, cellulose, and pectinase) as well as comparing the reducing sugar yield. The study reveals that microbial hydrolysis yield

more reducing sugar compared to the product of their enzymes (Mohammed *et al.*,2013), thus, confirming the potentials of microbial cells as better tools for reducing sugar production compared to crude enzymes produced from the same cells.

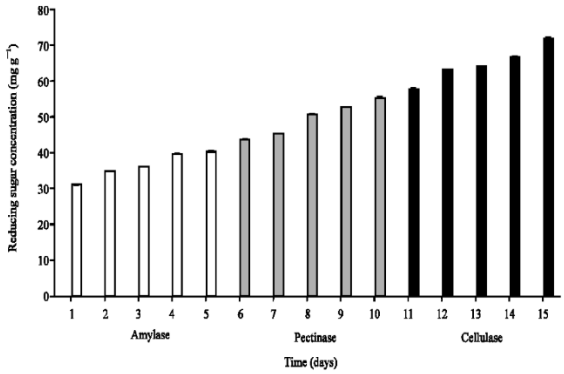

Figure 8. Reducing sugar yield from enzymatic hydrolysis of treated cassava peels, Level of significance p>0.05.

2.1.4 EFFECT OF ALPHA-AMYLASE ON FOOD INDUSTRIES

• **Production Alpha-amylase:** Various food industries need malty agent for different purposes so as to improve general quality of the end product. These malty agents are product of enzymatic action of alpha amylase and are usually imported to meet their demands in Nigeria industries. Having known this, our study group was able to produce the enzyme, alpha amylase, from Acha (*Digiteria exilis*) and subject it to immobilization, a process which improves stability, enzyme half-life, and maximizes turn over (Egwim & Oloyede 2011). After different trials, it was confirmed that, the locally produced malty agent can compete with the imported ones favourably. In another study by our research team, where the effect of sprouting on amylases activities and amylose content of FARO rice varieties

was determined, it was noted that sprouting increased the amylase activities of the rice samples while it decreased the amylose content of the sample. A sustained rise was noticed in the α- amylase, β- amylase and glucoamylase activities of the FARO rice samples over a long period during sprouting which indicates a high yield in the activities of these enzymes making them a better source of amylases. This study shows that the sprouting of our locally breed grain could be a potentially useful raw material in our food industry (Onukogu et al., 2022).

2.2 APPLICATIONS OF ENZYMES IN LEATHER AND TEXTILES INDUSTRY

The production of leather involves multiple steps, including tanning, where bating is used to enhance malleability and softness. Bating materials contain proteases that break down proteinaceous components by removing inter-fibrillary proteins (Puvanakrishnan et al., 2019). Acid protease from *Aspergillus usamii* has proven more effective for sheep pelts than neutral protease, and enzyme preparations active in acidic mediums are suggested for bating pelts treated with peracetic acid (Valeikiené 2006). However, proteolysis must be controlled to prevent leather damage. Papain, combined with soluble silicates, serves as a depilatory, improving leather smoothness while reducing chrome-bearing leather waste (Saravanabhavan et al., 2004). Enzymes such as amylases, catalases, and laccases are gaining recognition in textile processing due to their eco-friendly nature. They assist in starch removal, hydrogen peroxide degradation, textile bleaching, and lignin breakdown. Recent advancements include the use of cellulases for denim finishing and lactases for textile effluent decolorization. Papain has also been used to process wool, refine silk, and "shrink-proof" wool by partially hydrolyzing scale tips, enhancing silkiness and luster (Freddi et al., 2003). In textile bleaching, peroxide bleaching is preferred over chlorine due to its lower toxicity. Traditional reducing

agents like sodium bisulfite neutralize residual hydrogen peroxide but require high temperatures and extensive rinsing. Catalase offers an efficient alternative by breaking down hydrogen peroxide into water and oxygen at low temperatures, saving energy and eliminating wastewater pollutants, making the process more sustainable. Catalase treatment reduces water consumption from 30–40 liters per kg of fabric to almost none, significantly lowering the environmental impact.

leather products (This technology has also been patented)

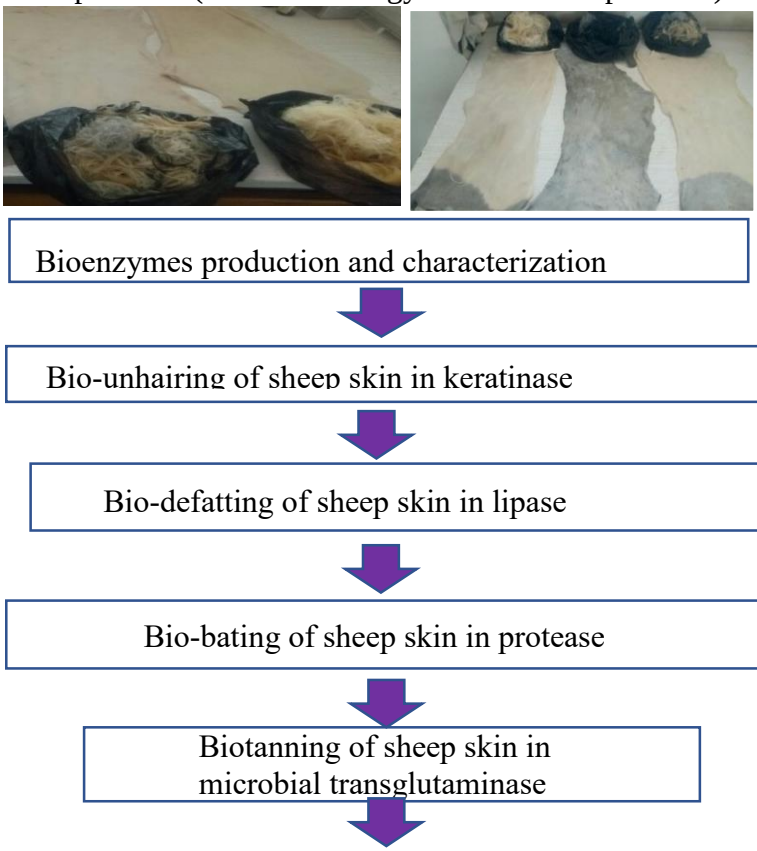

Fig. 10 A complete bio-process for leather production

APPLICATION OF ENZYMES IN BIOSENSING

Catalase is also a heme-containing redox enzyme known for its ability to degrade H_2O_2 (Zámocký & Koller 1999). This catalytic degradation takes place in two-steps: Firstly, H_2O_2 is reduced into water with the concomitant oxidation of the catalase heme Fe^{3+} to an oxyferryl species ($Fe^{4+}=O^{+}$), and second molecule of H_2O_2 is reduced into water and oxygen with the associated reduction of the oxyferryl species that regenerates the heme Fe^{3+}. Electrochemical biosensors applicable to various industrial niches have been developed using catalase (Mello & Kubota 2007, Modrzejewska et al., 2007). In the food industry, catalase is used as a biosensor for the detection of various chemicals mixed with food items. For example, Clark type electrode was developed by Sezginturk *et al.* (2005) using catalase enzyme for the detection of azide. Sodium azide is a chemical which is poisonous and highly toxic which is used in agriculture to control the pests. This chemical is also used as preservative in the laboratories, hence, may be mixed with fruit juices like black cherry juice, orange juice and apricot juice.
Another enzyme catalase biosensor was fabricated by a group to determine H_2O_2. The enzyme was cross-linked with $[Zn^{II}Al^{III}(OH)_2]^{+}NO_3^{-}$ Layered Double Hydroxide (LDH), which was glued on a glassy carbon electrode. The amperometric response to hydrogen peroxide was studied. A limit of detection of about 0.20 mM and a good lifetime as high as 75 days were observed (Tomassetti *et al.*, 2021).

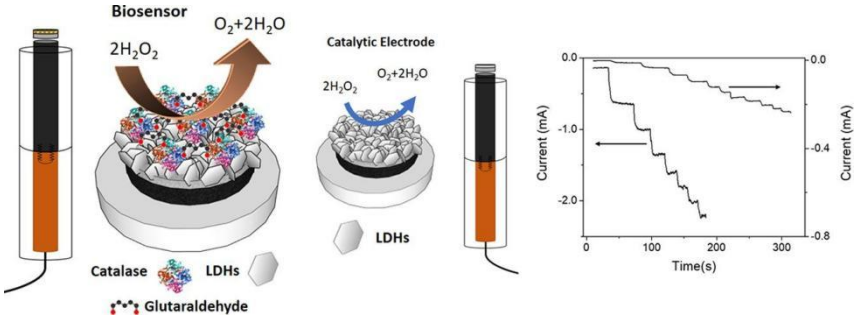

Figure 11. Schematic representation of a catalase Biosensor.

In the dairy industry, modern biosensing systems utilizing catalase have been developed for various applications. One such system immobilizes catalase on dissolved oxygen using gelatin to determine the extent of H_2O_2 decomposition in milk products. Another catalase-based biodevice, where the enzyme is immobilized on a Teflon membrane, has been designed to detect calcium levels in water and milk, with a detection range of 1–10 mM within one minute. Additionally, a catalase-based device has been developed to assess bacterial contamination levels, and another method uses catalase activity to detect and eliminate food-borne pathogens like *Listeria monocytogenes* and *Staphylococcus aureus* (Patel & Beuchat 1995, Majumdar et al., 2012). A CIC-biosensor, based on collagen-immobilized catalase and a dissolved oxygen probe, has been employed for H_2O_2 detection in milk, showing optimal performance at pH 7.0 and 30°C. It responds to H_2O_2 concentrations from 1.47×10^{-6} to 2.94×10^{-4} mol/L within 20–120 seconds and can be reused up to eight times. When applied in milk, the biosensor achieved H_2O_2 recovery rates of 83.4–95.8%, making it a promising tool for rapid, sensitive, and simple H_2O_2 detection.

2.2.1 APPLICATION OF ENZYMES IN COSMETIC PRODUCTS

Coenzymes and cofactors in cosmetics enhance enzyme function in the skin, promoting a healthy appearance by penetrating the stratum corneum and ensuring enzyme activation. They are stable, safe, and easy to formulate. Proteases like hyaluronidase, papain and bromelain treat skin issues such as aging, acne, and pigmentation. Acting as antioxidants, enzymes protect against free radicals from pollution, bacteria, and sunlight. Superoxide dismutase (SOD) and catalase prevent protein oxidation and aging by converting reactive oxygen species into less harmful forms, ensuring cellular protection in the skin.

Table 2.1: Use of Enzymes in Cosmetic products

Enzyme	**Source**	**Applications in Cosmetics**
Protease	Fungi	Peeling/anti-aging/antiwrinkle
Lipases	Bacteria	Anti-cellulitis
Hyaluronidase	Bacteria	Moisturizing agent
Tyrosinase	Yeast (Recombinant) *Tenebrio molitor* Fungi	Tanning agent
Superoxide dismutase	Yeast (Recombinant)	A star ingredient in anti- ageing formulas for its protective action against oxidative stress
Peroxidase	Horseradish, bacteria and yeast (recombinant)	Prevents cosmetic formulations from bacterial attack. This system is based on

		enzymes that consume the oxygen present in a formulation. Also serve as anti-free radicals
Alkaline phosphatase	Yeast and Fungi	Anti-wrinkle
DGAT-1, diacylglycerol acyltransferase	Bacteria	Boosts the action of retinoic acid which accelerates epidermis and hair renewal
Lysyl and prolylhydroxylases	Bacteria	Synthesize collagen necessary to maintain the structure of the skin (they need vitamin C to function)
Catalases	Vegetable	Serve as anti-aging in combination with SOD

2.3.1 Melanin Oxidation—Novel Cosmetic Lightening Agents

Melanin, produced through melanogenesis in melanocytes and stored in melanosomes, determines skin and hair color by transferring to keratinocytes in the epidermis (Mauricio et al., 2011). Its deficiency causes disorders like albinism, while excess melanin leads to hyperpigmentation (Kindred et al., 2013; Simon et al., 2009). Melanin exists as eumelanin (brown/black) and pheomelanin (red/yellow), with eumelanin being more prevalent in mammals (Khammuang & Sarnthima, 2013). Beyond mammals, melanin protects various life forms from environmental stress and enhances bacterial antibiotic

resistance (Kogej et al., 2007; Liu & Nizet, 2009). In humans, melanin shields tissues from UV radiation (Krol & Liebler, 1998), but many individuals seek skin-lightening treatments. Cosmeceutical industries have developed methods to inhibit melanogenesis, such as tyrosinase inhibition, preventing melanocyte stimulation by UVA radiation, and blocking melanosome transfer (Mauricio et al., 2011). Hydroquinone remains a gold standard for hyperpigmentation treatment, though its safety is controversial (Kindred et al., 2013), leading researchers to explore alternative agents like mequinol, azelaic acid, arbutin, kojic acid, licorice extract, and niacinamide, which primarily inhibit tyrosinase (Sheth & Pandya, 2011). However, tyrosinase inhibition is slow, prompting interest in agents that directly decolorize melanin through oxidation, such as ligninolytic enzymes.

Lignin peroxidase (LiP), capable of oxidizing diverse substrates, has been explored as a cosmetic lightening agent due to its ability to degrade melanin, similar to lignin. Ayodeji (2016) demonstrated that crude LiP from *Phanerochaete chrysosporium* effectively decolorized synthetic melanin, suggesting its potential in skin-lightening formulations. Studies have shown that LiP-based creams lighten skin more effectively than 2% hydroquinone cream, with superior texture and no adverse effects (Draelos, 2015; Mauricio et al., 2011). LiP's action involves five steps: oxidation by hydrogen peroxide, reduction by veratryl alcohol (VA) to form a VA radical, melanin oxidation mediated by VA radicals, LiP inactivation due to skin pH changes, and hydrolysis of the inactivated enzyme into amino acids by skin proteases. Further research is needed to compare LiP-based creams with higher hydroquinone concentrations and assess their effectiveness against various pigmentation disorders.

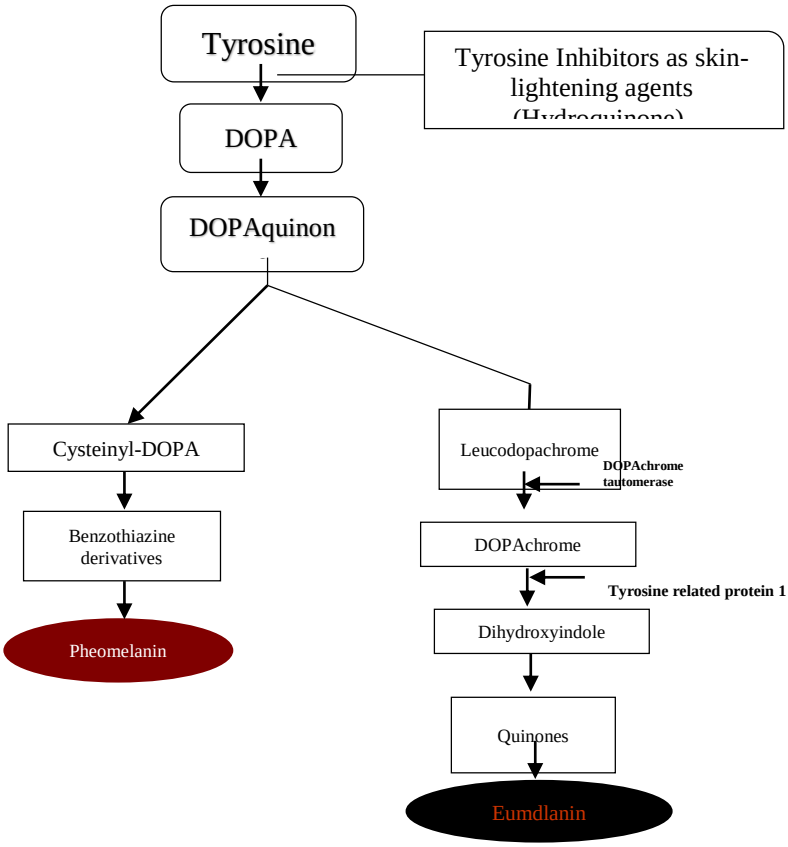

Figure 12. (A) Melanin biosynthesis pathway

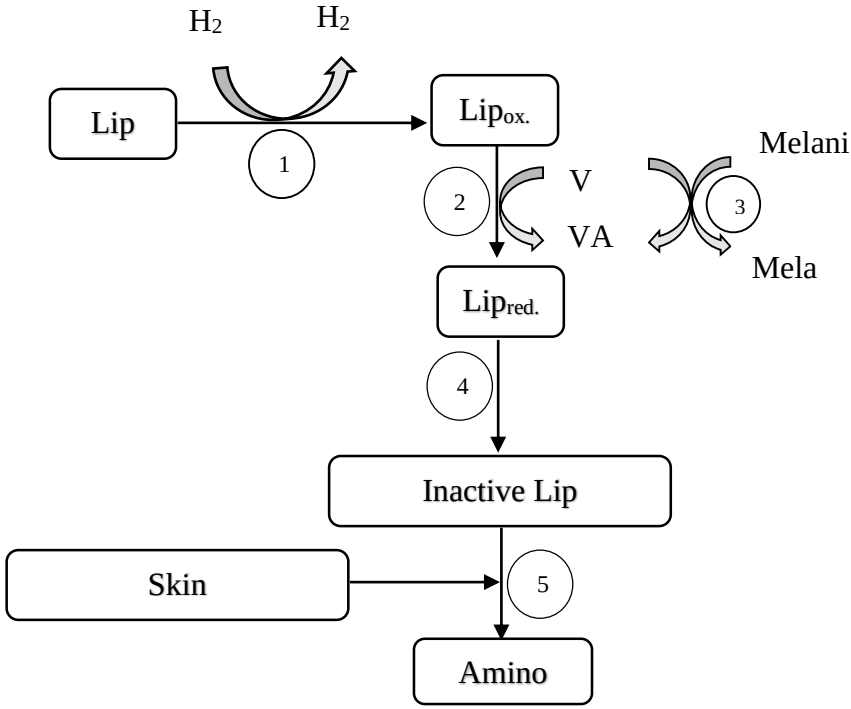

Figure 12. (B) Mechanism of action of lignin peroxidase as cosmetic lightening agent

2.2.2 APPLICATION OF ENZYMES IN SOLID WASTE (PAPER AND PULP) MANAGEMENT

The Kraft process in wood pulping leaves behind residual lignin, responsible for the brown color of pulp, which is typically removed using chlorine-based bleaching agents. These processes generate toxic, mutagenic effluents that pose environmental hazards. Enzymes such as peroxidases and laccases have shown promise in treating these effluents. LiP from *P. chrysosporium* degrades lignin by oxidizing aromatic

units, while laccase polymerizes low-molecular-mass phenols for removal. Immobilized forms of these enzymes have demonstrated superior efficiency in decolorization compared to their free forms (Ferrer et al., 1991; Rogalsk, 1991).

Peroxidases (EC 1.11.1.7) catalyze peroxide reduction and oxidize various organic and inorganic compounds (Hamid, 2009; Chanwun et al., 2013). They have applications in wastewater bioremediation, biopulping, biobleaching in the paper industry, and textile dye degradation (Chandra et al., 2011; Huber & Carré, 2012). White rot fungi leverage extracellular peroxidases to degrade lignin and environmental pollutants such as dioxins, PCBs, petroleum hydrocarbons, and pesticides (Lundell et al., 2010; Marco-Urrea & Reddy, 2012). A specific peroxidase from *Agaricus* fungi can oxidize dyes and phenols (Hofrichter et al., 2010), further demonstrating the enzyme's broad applicability in environmental cleanup.

2.2.3 APPLICATIONS OF ENZYMES IN BIOFUELS

With the depletion of non-renewable resources, biofuels such as biodiesel, bioethanol (Omonije et al., 2021), biohydrogen, and biogas are being explored as sustainable alternatives to fossil fuels. These biofuels are considered CO_2-neutral and produce lower emissions of particulates, carbon oxides, and sulfur oxides compared to fossil fuels (Al-Zuhair et al., 2011). Enzymes play a critical role in improving biofuel quality, efficiency, and production by overcoming the limitations of conventional chemical catalysts. For example, enzymatic biodiesel production consumes less energy and allows the use of unrefined feedstocks, such as waste oil, without the need for free fatty acid removal. Similarly, enzymatic hydrolysis of cellulose to fermentable sugars for bioethanol production is more cost-

effective than acidic hydrolysis due to its mild conditions and reduced post-treatment requirements. D d

Lipases (EC 3.1.1.3), found in animals, plants, and microorganisms, are widely used for biodiesel production through enzymatic transesterification of vegetable oil and animal fat. Microbial lipases, such as those from *Burkholderia cepacia* (Saso et al., 2016) and *Pseudomonas fluorescens*, are preferred due to their high stability and cost-effectiveness, while *Candida antarctica* lipase B is commonly used from yeast. Fungi have also been utilized in biofuel production (Srivastava et al., 2018). Enzyme immobilization using substrates like mesoporous silica enhances industrial applications (Costantini & Califano, 2021). Additionally, laccase (EC 1.10.3.2), a multi-copper enzyme, facilitates biofuel production by oxidizing substrates such as diphenols and amines, producing radicals that contribute to bioconversion. Laccase specifically targets lignin in bioethanol and biogas production (Kudanga & Roes-Hill, 2014). Cellulases are extensively used in biofuel industries for breaking down cellulose into fermentable sugars essential for bioethanol and biohydrogen production. Produced by bacteria and fungi, cellulases from fungal species like *Aspergillus niger*, *Aspergillus fumigatus*, and *Trichoderma* spp. are preferred due to their complete cellulase systems. Effective cellulose conversion requires the combined action of three enzymes: Beta-1,4-endoglucanase, Beta-1,4-exoglucanase, and Beta-D-glucosidase. Lignocellulose has also been used in butanol production (Patience & Egwim, 2021), further demonstrating the role of enzymatic processes in advancing biofuel technology.

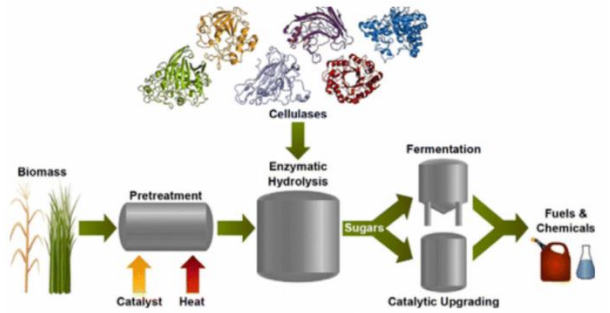

Figure 13. Overall view of a conventional biochemical conversion process to produce fuels and chemicals from lignocellulosic biomass

2.3 BIODIESEL PRODUCTION

i. Optimization Of Biodiesel Production from Daniella Oliveri Oil Seed Using Waste

Snail Shell as Heterogeneous Catalyst: Biodiesel has gained support and recognition as a fuel to replace fossil fuel which has caused a lot of damage to the environment. In search of locally cheap raw materials that could be used for biodiesel production at a cheaper rate. An investigation was carried out with Daniela oliveri oil seed and waste snail shells as raw materials (Otoei et al., 2021). The extracted oil from D. oliveri seed was transesterified with CaO prepared from the snail shell as heterogeneous catalyst. The optimum biodiesel yield was found as high as 77% with four optimize parameters playing active roles; methanol to oil ratio (7:1), temperature 500C, catalyst concentration (2.0 wt %) and reaction time 60 min to achieved optimum biodiesel yield. The produced biodiesel properties were compared with the standard and some of the properties are in line with ASTM standard for biodiesel. The waste snail shell had high

potential as cost effective heterogeneous catalysts than the convectional (KOH and NaOH) for biodiesel production. D oliveri oil seed is a promising feedstock for biodiesel production.

ii. **Optimization Of Lipase Immobilized on Chitosan Beads for Biodiesel Production**: Lipases are enzymes that catalyze the hydrolysis of ester bonds at a lipid-water interface. In a study by Egwim et al. (2012), lipase was immobilized on a chitosan bead for the purpose of biodiesel production. This involved immobilization of lipase by physical adsorption on chitosan following Carneiro da Cunha et al., (1999) methodology, followed by assessment of lipase protein concentration, activity and characterizations. The study concludes that immobilized lipase provides important advantages such as easy separation from the product conferring a high potential for reuse, high storage stability. The impacts of the above advantages are that immobilization of enzyme drastically reduce direct biodiesel production cost. Thus, immobilized lipase can be used for the development of a bioreactor for use in commercial biodiesel production.

2.3.1 APPLICATION OF ENZYMES IN AGRICULTURE AND ANIMAL FEED

Enzymes play a vital role in agriculture, particularly in soil transformation, nutrient cycling, and as feed additives, contributing to ecosystem stability and improved livestock digestion (Joseph et al., 2022). They are used as natural pesticides, herbicides, fertilizers, and odor removers, helping to reduce farm odors and repel insects. Phytases, a subgroup of phosphatases, facilitate the stepwise dephosphorylation of phytic acid (myo-inositol hexakisphosphate) to release inorganic phosphorus, addressing phosphorus deficiency in non-

ruminant animals such as humans, dogs, swine, and poultry, while mitigating environmental phosphorus pollution in intensive farming (Balwani et al., 2017). Carbohydrases, another crucial enzyme group, enhance food assimilation by improving carbohydrate digestion, leading to increased muscle mass in livestock. These enzymes are widely used in pig diets (Kim et al., 2006) and have been applied in protein extraction from rice bran (Hourigan & Chesterman, 1997).

2.3.2 PURIFICATION AND CHARACTERIZATION OF AN ACIDOPHILIC CELLULASE FROM *PLEUROTUS OSTREATUS* AND ITS POTENTIAL FOR AGROWASTES VALORIZATION

In our study, cellulase from Pleurotus ostreatus mycelia was purified through ammonium sulfate precipitation (85% saturation) and gel filtration chromatography, yielding a specific activity of 61.0 U/mg and 17.9% recovery. SDS-PAGE confirmed its homogeneity. The enzyme exhibited optimal activity at pH 4.0 within an acidic range of 3.0–5.0 and remained stable between 40–65°C, with an optimum temperature of 55°C, indicating thermophilic properties. Given the industrial demand for thermophilic and acidophilic enzymes due to their stability and efficiency, P. ostreatus cellulase holds significant commercialization potential.

1. **HYDROLYTIC POTENTIAL OF PURIFIED CELLULASE ON SELECTED AGROWASTES**

   The production of bioethanol from biomass begins with hydrolysis to produce reducing sugars which are then fermented to alcohol (Keshk 2016). In our study, some commonly generated agro wastes in Nigeria were used as substrates for the purified enzyme (Okereke *et al.*, 2017). The results (Table 1) showed that the purified cellulase hydrolyzed cassava peel, corn cob, rice husk

and groundnut shell appreciably. The purified cellulase was able to hydrolyze these agro-wastes without prior chemical pre-treatment which could be as a result of the high cellulose and the low lignin content of these agro-wastes (Aripin *et al.,* 2013).

Table 2.2: Activity of the purified cellulose from *Pleurotus ostreatus* on selected agrowastes (Okereke *et al.*, 2017)

Substrate	**Activity** (U)
Corn cob	19.9 ± 0.1
Cassava peel	22.9 ± 0.4
Groundnut shell	17.3 ± 0.7
Rice husk	17.8 ± 1.6
Melon seed coat	13.3 ± 2.8
Values are presented as mean ± standard deviation of three replicates.	

2.3.3 PRODUCTION OF LIVESTOCK FEED

Rising grain costs and increasing demand for animal protein have intensified debates on using food grains for livestock. As incomes rise, diets shift toward animal-based products, driving up grain prices, which disproportionately affect poorer consumers (Warmington & Kirton 1990; Kosum et al., 2003). High-concentrate diets improve growth rates, carcass quality, and meat yield, benefiting household incomes (Mtenga & Kitaly 1990). However, reliance on forage alone may not support optimal weight gain (Kochapakdee et al., 1994), necessitating alternative feed sources, especially in dry seasons. Sawdust and poultry feather waste are potential options. Sawdust, a by-product of sawmills, can become an environmental hazard if not managed properly (Eze et al., 2011). Enzymes improve digestion of various feedstuffs by enhancing microbial activity in the rumen (Beauchemin et al., 2003; Nsereko et al., 2000; Morgavi et al., 2001; Yang et al., 1999). Our research developed

Bacillus strains native to tropical environments for keratinase production, enabling efficient poultry feather waste degradation and reducing reliance on imported enzymes.

Fig. 14: Feather meal produced with keratinase was used to feed birds to table size within 6weeks. NRF Project

In another experiment, our research team developed an enzyme, cellulase and pectinase which was used to hydrolyze corn cob and used to feed broiler chiken at 5 to 15% inclusions. At the end of the experiment, the enzyme treated chicken weighed 2383.38g compared to control fed with normal diet which weighed 1666.67g. Chickens fed enzyme treated corncob diets also had higher dressing percentage (80.22% versus 73.93% ± 0.71), higher cut-up parts and organ proportions. The result showed that locally produced cellulase and pectinase hydrolyzed corncob diets at 5 to 15 % levels improved broilers performance and carcass quality. It was concluded that for optimum performance, enzyme treated corncob could be included in diets of broiler chickens up to 15 % level. (Tsado *et al.*, 2019)

2.3.4 APPLICATIONS OF ENZYMES IN ENVIORNMENT

Lipases are hydrolytic enzymes responsible for the hydrolysis of triacylglycerol into glycerol and free fatty acids.

• **Production of Lipase from crude oil contaminated soils:** In a study by our research group, the biodiversity of crude oil contaminated soil was explored for the isolation of novel potent lipase producing microorganisms (Elemuo *et al.,* 2022). Microorganisms isolated from crude oil contaminated soils were screened for lipase activity and expression. Six fungal strains namely: Yeast, *Aspergillus flavus*, *Aspergillus niger*, *Verticillus sp., Penicillum sp., and Microsporum audouini* demonstrated lipase producing potentials and the best two: *Verticillus* sp. and *Penicillum* sp. were selected for enzyme production and characterization. The lipase enzyme was produced in broth medium. The fungal strains *Verticillus sp*. and *Penicillum* sp. isolated from crude oil contaminated soils were established to be potent lipase producers. The lipase enzyme had a high activity and was very stable at diverse temperature and pH ranges with vast affinity for numerous substrates. These findings uncover novel sources for microbial lipases that could be applied for numerous industrial applications.

Table2.4: Zone of clearance produced around fungal colonies for lipase production (Elemuo *et al.*, 2022).

S/N	Name of Organism	Zone of clearance (mm)
1.	Yeast	1.00
2.	*Aspergillus Flavus*	7.67
3.	*Aspergillus Niger*	6.88
4.	*Verticillus sp.**	13.45
5.	*Penicillum sp.**	11.23
6.	*Microsporum audouini*	4.70

Applications of Lipase in oil prospecting

In a study by our research team, lipase enzymes LPE1 and LPE2, produced from crude oil-contaminated soil isolates *Verticillium* sp. and *Penicillium* sp., were investigated for their effects on wettability, interfacial tension, and adhesion behavior in a crude

oil/brine/solid system. The lipases altered the system's wettability to a water-wet state, as indicated by contact angle measurements, and changed oil adhesion on glass slides from adhesive to non-adhesive behavior. However, no significant change in interfacial tension was observed. These findings suggest that microbial lipases enhance oil recovery and are more efficient than conventional chemical methods in modifying crude oil behavior in reservoirs (Elemuo et al., 2019a).

Fig. 15: Adhesion Behaviour of Crude Oil X2 at pH 4 and 0.5M Salt Concentration by LPE1 Enzyme Introduction.

i. **Plastic Degradation**: In another study by our research team, extracellular lipase and esterase expressed by dumpsite microorganisms for the degradation of low density plastic were evaluated. The degradation ability of the organisms was monitored spectrophotometrically at interval of 10 days for a period of 30 days. In evaluating the enzymes lipase and esterase produced by the microbial isolates efficient in the degradation of low-density polyethylene, the enzyme lipase was assayed by spectrophotometric method with tween 80 as substrate. The difference in absorbance of the sample solution from the initial absorbance at day 0 corresponds to the growth of microorganisms, with increase absorbance relating to increase microbial growth rate which indicates the utilization of low-density polyethylene as sole carbon source. The different strains of microorganisms responded to the degradation of low-density polyethylene at different growth rate.

Table 2.5: Some bacterial and fungal enzymes/strains involved in biodegradation of both biodegradable and non-biodegradable plastics.

Sources	Enzymes	Microorganisms	Plastic	References
Bacteria	Lipase	*Rhizopusdelemar*	PCL	Abou-Zeid *et al.*, (2001), Tokiwa *et al.*, 2009
	Unknown	*Firmicutes*	PHB, PCL, and PBS	Tokiwa *et al.*, 2009
	Lipase	*R. arrizus*	PEA, PBS, and PCL	Tokiwa *et al.*, 2009
	Serine hydrolase	*P. stutzeri*	PHA	Muhamad *et al.* (2015)
	Unknown	*B. borstelensis*	PET	Cruz-Romero & Kerry (2008)
	Unknown	*Pseudomonas fluorescens B-22*	PVC	Danko *et al.* (2004)
		P. putida Ochrobactrum TD		
	Manganese peroxidase	*Phanerochaete*	Polyethylene	Shimao (2001)
	Cutinase	*chrysosporium*	PCL	
Fungi	Unknown	*Fusarium*	Polylacticacid (PLA)	
	Cutinase	*Amycolaptosissp.*	Polybutylene succinate (PBS)	Maeda *et al.* (2005)
	Lipase	*Aspergillus oryzae*	PCL	Tokiwa *et al.* (2009)
	Catalase	*Rhizopusdelemar*	PCL	Tokiwa *et al.* (2009)
	protease	*Aspergillus niger*	Polycaprolactone (PCL)	Tokiwa et al. (2009)
	Glucosidases	*Aspergillus flavus*	Polyethylene adipate (PEA)	Tokiwa *et al.* (2009)
	Lipase	*Penicillium, Rhizopusarrizus Trichoderma sp.*	PBS, PCL	Tokiwa *et al.*, (2009)
	Urease	*Pestalotiopsis microspora*	Polyurethane	Garcia *et al.* (2011)
	Serine hydrolase		Polyurethane	Russell *et al.* (2011)

It was observed from the statistical analysis done for the degradation rate of the bacterial isolates (Fig.5) that the four strains of bacteria identified, Acinetobacter, Klebsiella, Pseudomonas and Bacillus had a rapid increase in growth as at day10. However, Acinetobacter and Klebsiella experienced repression in growth after another interval of ten days, at day 20 and day30. Pseudomonas and Bacillus experienced continuous increase in growth rate throughout the degradation period as the spectrophotometric readings of Pseudomonas increased from 2.388 at day 10 to 2.392 at day 20 to 2.439 at day 30 while that of Bacillus increased from 2.445 at day 10 to 2.529 at day 20 to 2.565 at day 30 respectively.

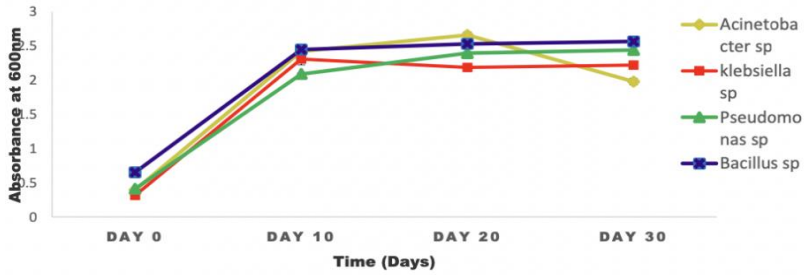

Figure 14 (A): Degradation Rate of Low -density Polyethylene by Bacterial Enzymes

It was observed from the spectrophotometric readings of the sample solution at an interval of 10 days for a period of 30 days that the fungal strains identified are quite different in their degradation rate of low-density Polyethylene. Similar to the bacterial strains identified, the statistical analysis of the fungal growth rate as shown in figure 12 depicted that the fungal strains showed an increase in growth at day10 as compared to the initial indicative of the utilization of low-density polyethylene as sole carbon source for energy and growth, while their growth rate

differed largely. The growth rate of Trichophyton sp decreased continuously throughout the period of degradation, while the growth of Monilia sitophila was quite clumsy, as the growth rate increased at day 10, decreased at day 20, and increased at day 30. However, the growth rate of Penicillium notatum, *Cryptococcus neoformans*, *Fusarium*, *Aspergillus fumigatus* and *Fonsecaea pedrosoi* increased significantly during the period of degradation, which indicates that these organisms are efficient in biodegradation of low density polyethylene. As compared to these organisms, Aspergillus fumigatus and Fonsecaea pedrosoi proved to be more efficient in the biodegradation of low-density Polyethylene with the highest microbial growth rate.

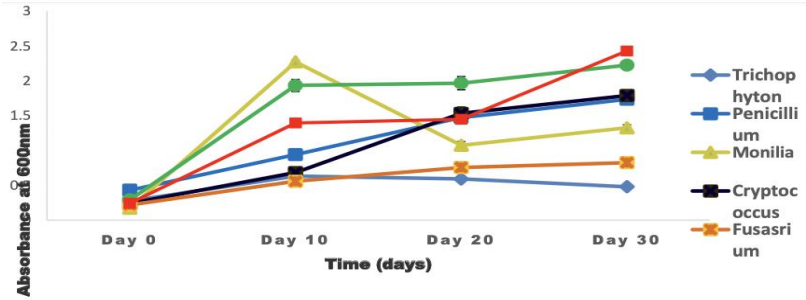

Figure 14 (B): Degradation Rate of Low-Density Polyethylene by Fungal Enzymes

The enzyme lipase was assayed for the bacterial isolates efficient for the biodegradation of low-density Polyethylene, *Pseudomonas* and *Bacillus*. It was evident from the result (fig 6) that *Pseudomonas sp* had a high enzyme activity for day 10, and day30 as compared to *Bacillus*, with the highest enzyme activity found at day 10.

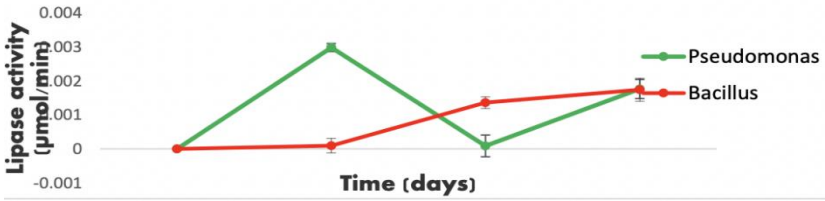

Figure 14 (C): Activity of Lipase Expressed by Selected Bacterial enzymes for the Degradation of Low-Density Polyethylene

The result observed for the enzyme activity of the fungal isolates that were more efficient in biodegradation of low-density Polyethylene indicated that *Penicillium notatum* had no enzyme activity. *Cryptococcus neoformans* also had no lipase enzyme activity throughout the degradation period, this was apparent from the negative values of enzyme activity at day 10, day 20, and day30. *Fusarium sp*, *Aspergillus fumigatus* and *Fonsecaea pedrosoi* however had a significant increase in enzyme activity from day 10 to day 30.

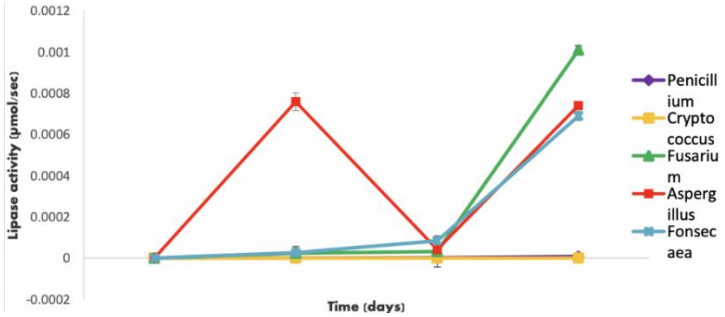

Figure 14 (D): Activity of Lipase Expressed by Selected Fungal enzymes for the Degradation of Low-Density Polyethylene.

2.3.5 HEAVY METALS BIOSORPTION BY UREASE PRODUCING LYSINIBACILLUS FUSIFORMIS 5B

In a study by our research group aimed at determining the potential of *Lysinibacillus fusiformis* 5B to biosorp Pb, Cr, Cd, and Ni across all concentrations (i.e. 10, 15, 20 and 50ppm) (Jibrin *et al.*, 2020). After seven days of incubation, the result obtained showed high rate (> 40%) of biosorption of heavy metals (Cd, Cr, and Pb) across the concentration considered with the exception of nickel (Ni). *Lysinibacillus fusiformis* 5B was observed to have the capacity to biosorp cadmium, chromium, lead and nickel with increasing capacity as the days of incubation progressed. Thus, the urease produced from this isolate was explored for detecting heavy metals in the environments thereby help to reclaim these environments of heavy metals toxicity. Using urease immobilized on paper to detect lead (Pb) is shown in plate.15

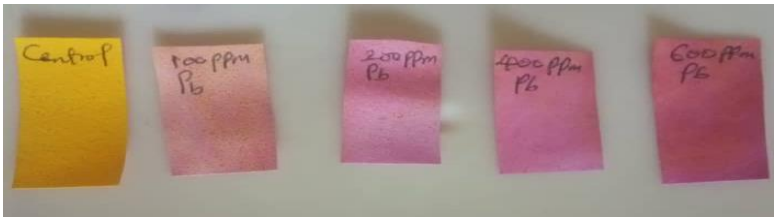

Plate . 15 colour chat of different concentrations of Pb dictated by urease immobilized on paper

Zymocrete: Enzymatic Innovation for Stronger, Cost-Effective Construction

Enzymes are revolutionizing materials science, particularly in construction, we have developed Zymocrete—an enzymatic formulation that enhances the strength and durability of cement concrete and clay bricks. This innovation allows a 30% reduction in cement usage while tripling the strength of

materials, significantly lowering energy consumption in brick curing. Moreover, Zymocrete enables underwater casting, overcoming washout issues faced by traditional concrete, making it ideal for marine and submerged infrastructure projects. By reducing material costs and energy demands, this breakthrough supports sustainable and eco-friendly construction practices.

Zymocrete has been patented for its transformative potential, it exemplifies the expanding role of enzymes in industrial applications, reinforcing their versatility as the ultimate "Jack of all trades." It minimizes carbon emissions from cement production while maintaining superior mechanical properties, aligning with global sustainability goals. The advent of bioengineered solutions like Zymocrete marks a paradigm shift in construction, demonstrating how enzyme technology can drive innovation across multiple industries.

Plate 16 Cement concretes and clay bricks processed with zymocrete. The samples were 3x stronger than conventional concretes and clay bricks

CONCLUSION

Enzymes play a crucial role in agriculture-based industries like dairy, fisheries, poultry, and food processing, as well as in fuel, pharmaceuticals, medicine, cosmetics, and construction. Used in beverage manufacturing since ancient times, enzymes offer excellent catalytic properties with minimal side reactions and require lower quantities than conventional catalysts. Their eco-friendly nature makes them valuable in food production, biofuel synthesis, drug development, disease diagnostics, skincare formulations, and biodegradable building materials. Advances focus on designing more stable enzymes, less dependent on metal ions and resistant to inhibitors. Immobilization enhances enzyme efficiency, though standardized selection criteria for carriers remain lacking. As natural resources dwindle and populations grow, enzyme technology holds great potential for sustainable industrial and medical applications.

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Together, you have created a legacy of innovation and impact. Your research has not only advanced our field but has also demonstrated the power of collaboration, hard work, and unwavering determination. You have proven that no goal is too ambitious when pursued with heart and intellect.

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12. In-laws: I want to sincerely thank my in-laws. The Ozore family. It has been a wonderful journey of love. Thank you for accepting and supporting me

13. My siblings: I sincerely appreciate my siblings for their unwavering support, encouragement, and belief in my journey. Your love, patience, and constant motivation have been a source of strength and inspiration. Through every challenge and success, your presence has been a reminder of the value of family and the power of shared dreams. I am grateful for your prayers, understanding, and the countless ways you have stood by me. This work is a testament to the bond we share, and I deeply cherish each of you.

14. Special parents: I have two different parents in my journey of life. I want to thank the family of pastor (late) and Mrs Andrew Jaja who received and nurtured me from my arrival in Niger State and Pastor and pastor Mrs Sunday Akoh who nutured me throughout my postgraduate sudies till now. I appreciate your love and for accepting me into your family.

15. Parents: To my beloved parents, Mr. and Mrs. Egwim, though you are no longer here, your legacy lives on in every step I take. You saw the value of education even when the odds were against us, and you labored tirelessly to ensure I achieved my BSc. Your sacrifices, love, and unwavering belief in me have been the foundation of my success. I am forever grateful for the lessons you taught me, the strength you instilled in me, and the dreams you nurtured. This achievement is as much yours as it is mine, and I carry your memory with pride and gratitude every day. Thank you for everything.

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To my wonderful children, **Jeph and Jedidah Evans**, your joy, curiosity, and boundless love fuel my passion for learning and discovery. You remind me daily of the beauty of purpose and the importance of perseverance. Watching you grow into incredible individuals fills me with pride and drives me to be the best version of myself.

This journey would not have been the same without you all. You are my greatest blessings, and I dedicate this work to you with all my love.

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Profile of Professor Egwim, Chidi Evans, (FNSBMB)

Department of Biochemistry, Federal University of Technology, Minna, Niger State, Nigeria

Professor Egwim, Chidi Evans, is a distinguished academic, researcher, and innovator in the field of Industrial Biochemistry and Bioprocesses. With a career spanning over two decades, he has made significant contributions to the advancement of biochemistry, biotechnology, and sustainable industrial processes. His work has not only elevated the academic standing of the institutions he has served but has also had a profound impact on industries and communities both locally and internationally.

Academic and Professional Background

Professor Egwim holds a PhD in Biochemistry from the University of Ilorin, Nigeria (2006), a Master of Science in Biochemistry from the same institution (1999), and a Bachelor of Science in Biochemistry from the University of Lagos, Nigeria (1994). His academic journey reflects a relentless pursuit of knowledge and excellence, which has positioned him as a leading figure in his field.

Since 2007, he has been a Lecturer and later (2016) Professor of Industrial Biochemistry and Bioprocesses at the Federal University of Technology, Minna (FUT Minna). In 2023, he took on a Sabbatical Professor role at Caleb University, Lagos, further extending his influence in academia. His previous academic appointments include Visiting Professor at Bingham University, Karu, Nasarawa State (2008–2012), and Visiting Lecturer/Professor at Ibrahim Badamasi Babangida University, Lapai, Niger State (2013–2020). He also served as a Lecturer at the Federal Polytechnic, Bida, Niger State, from 1996 to 2007.

Research and Innovations

Professor Egwim's research focuses on cutting-edge areas such as:

Development of Edible Films and Biodegradable Materials: For the storage of tropical fruits and vegetables, addressing post-harvest losses.

Immobilized Enzymes: For industrial-scale production of glucose-fructose syrup, citric acid, and lactic acid.

Indigenous Enzymes: For meat and bread processing, promoting local solutions to industrial challenges.

Green Synthesis of Nano Composites: For antioxidant, anti-inflammatory, immunomodulatory, and anti-cancer properties.

Cancer, Malaria and Diabetes Biomarkers: Characterization of novel biomarkers for affordable and rapid screening kits.

His research group has developed several groundbreaking products, including:

Modified starches for pharmaceutical and food industries.

A complete bioprocess for leather processing.

Collagen production from fish waste.

Edible films and nano-zinc oxide composites for food storage.

Biodiesel production from underutilized feedstocks.

Microbial fuel cells for electricity generation and wastewater treatment.

Professor Egwim also heads the Energy Research Unit, focusing on renewable energy solutions such as lignocellulosic ethanol, biofuel stoves, solar appliances, nano wires and next-generation batteries.

Supervision and Mentorship

As a dedicated mentor, Professor Egwim has supervised and graduated 31 PhD students and 57 MTech students, with 6 PhD students currently under his guidance. His mentorship has produced a generation of scholars and professionals who are making significant contributions to science and industry.

Patents and Intellectual Contributions

Professor Egwim holds several patents, including:

1. NG/P/2023/26 - Concretes biocalcificer and compacted clay stabilizer from bacterial isolate (Zymocrete)

2. NG/P/2023/27 - Biosurfactant/ironoxide nanoparticle/biochar composites for bioremediation of crude oil polluted soil

3. NG/P2023/22 - Complete bio-process for leather making

4. NG/PT/NC/O/2024/14707: Bio-citric acid production from agro-wastes

5. NG/PT/NC/O/2024/14709: Bio-methionine production from agro-wastes Collaborations and Partnerships

Professor Egwim has established robust collaborations with both local and international institutions, including:

Vertex Agro Chemicals, Abuja.

National Cereals Research Institute (NCRI), Badeggi, Niger State.

Aman Russom, KTH Royal Institute of Technology, Stockholm, Sweden.

Samuel Egieyeh, University of the Western Cape, South Africa.

Carlo Bakker, Creaton4Change, Netherlands.

Nuno Escudeiro, ABC Blended Mobility, Portugal.

These collaborations have facilitated knowledge exchange, capacity building, and the development of innovative solutions to global challenges.

Publications and Citations

With an impressive academic output, Professor Egwim has published 200 research papers, garnering 2,910 citations. His h-index of 34 and i10-index of 63 underscore the impact and relevance of his work in the scientific community.

Awards and Recognitions

Professor Egwim's contributions have earned him numerous accolades, including:

African Life Science Award (2020).

National Industrial Personality Award (2021).

USAID Research Grant for Neglected Tropical Diseases.

Green Power Fellowship to South Africa.

MASHAV-Israel Research Fellowship in Biotechnology and Bioinformatics.

Research Grants and Funding

Professor Egwim has secured substantial research funding, including:

Over 10 TETFUND IBR and NRF grant awards

Administrative Leadership

Professor Egwim has held several key administrative positions, including:

African coordinator , Creaton 4 Change

Nigerian coordinator ABC Blended Mobilioty (Erasmus +)

Coordinator, AINNC west Africa

Director, Academic Planning Caleb university (2023–2023).

Director, Centre for Genetic Engineering and Biotechnology (2019–2023).

Head, Biochemistry Department (2016–2019).

Sub-Dean, School of Postgraduate Studies (2012–2013).

Coordinator, Research and Seminar, School of Life Sciences (2015–2018).

His leadership has been instrumental in driving institutional growth, fostering research excellence, and promoting interdisciplinary collaboration.

Conclusion

Professor Egwim, Chidi Evans, is a visionary scholar, a prolific researcher, and a dedicated mentor. His work bridges the gap between academia and industry, addressing critical challenges in health, agriculture, energy, and environmental sustainability. Through his innovative research, impactful collaborations, and unwavering commitment to excellence, he continues to inspire the next generation of scientists and contribute to the advancement of global knowledge.

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