Science World Journal Vol. 21(No 2) 2026 https://dx.doi.org/10.4314/swj.v21i2.33
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University

EXPLORING THE ENVIRONMENTAL AND INDUSTRIAL APPLICATIONS OF MICROBIAL LIPASES

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ABSTRACT

Microbial lipases are indispensable in modern environmental management and industry, offering eco-friendly, efficient, and cost-effective solutions across diverse sectors. Their broad specificity, high stability, and ability to catalyse reactions under mild conditions underscore their significance in promoting sustainable development and innovative industrial processes. As biotechnological advancements continue to garner momentum, the potential applications of lipases are expected to expand, further enhancing their role in shaping a more sustainable and environmentally conscious future. Lipases are universal enzymes of extensive physiological importance. They have a wide range of applications across industries, including food (dairy, fats and oils, beverages, and bakery), detergents, paper and pulp, biodiesel production, pesticides, pharmaceuticals, and bioremediation of various effluents. Microorganisms producing lipase are derived primarily from bacterial genera such as Bacillus, Pseudomonas, and Burkholderia, as well as fungal species such as Rhizopus, Aspergillus, and yeast-like Candida, enabling efficient production from diverse substrates, including agro-industrial wastes. Their broad substrate specificity, stability under extreme conditions, and ability to catalyze reactions such as hydrolysis, esterification, and transesterification underpin transformative applications across sectors. As global industries increasingly shift toward green technologies and sustainable processes, microbial lipases are expected to play an even more crucial role in addressing environmental challenges while supporting innovation and industrial development.

Keywords: Lipase, Biocatalyst, Eco-friendly, Enzymes.

INTRODUCTION

Enzymes are protein molecules, specialized biological catalysts that speed up the rate of biochemical reactions in living organisms. Each enzyme reacts only with a specific reactant (substrate) (Kiran *et al*., 2016). They catalyze the biochemical reaction that makes life possible (Choudhury & Bhunia, 2015). A variety of enzymes have been used for many centuries. In this decade, about 4,000 enzymes have been reported, of which only 200 are used commercially (Shamim *et al*., 2018). Enzymes are produced by living cells; they can also be extracted from organisms and used for industrial, pharmaceutical, and biotechnological applications (Borrelli & Trono, 2015). Enzymes play a pivotal role in all stages of metabolism and biochemical reactions. Microbial enzymes are preferred over chemical catalysts because they are highly specific, economical, easier to produce, and environmentally friendly (Shamim *et al*., 2018). Certain enzymes are significant for their potential as catalysts in various biochemical applications. One of these enzymes is lipase, a hydrolase that acts as a biocatalyst. Organisms producing this enzyme include plants, animals (particularly mammals), and microbes (preferred over other potential sources) (Mahboob *et al*., 2022). Lipase is a high-value compound due to its high rate of productivity. Properties such as specificity, stability, ease of genetic manipulation, shorter production periods, growth in inexpensive growth media, and the ability to grow at any time make microbial enzymes preferable over animal or plant enzymes (Shamim *et al*., 2018). It has a wide range of applications across industries, including food (dairy, fats and oils, beverages, bakery), detergents, paper and pulp, biodiesel production, pesticides, pharmaceuticals, and bioremediation of various effluents (Mahboob *et al*., 2022). It plays a crucial role in the digestion, transport, and processing of lipids across most living organisms. Their versatility allows them to catalyze a variety of bioconversion reactions, including hydrolysis, alcoholysis, acidolysis, aminolysis, esterification, and interesterification, in both unicellular and multicellular entities (Abdelaziz *et al*., 2025). Microorganisms producing lipase have been found in diverse habitats, including industrial waste, vegetable oil processing factories, dairies, oil-contaminated soil, oilseeds, decaying food, compost heaps, coal tips, and hot springs. Lipases are produced by many microorganisms, including bacteria, fungi, yeasts, and actinomyces (Hasan *et al.,* 2018). The most common bacterial sources for lipases include *Bacillus* spp., *Pseudomonas* spp., *Staphylococcus* spp., and *Burkholderia* spp. Bacterial lipase catalyzed the most types of hydrolytic reactions with lipase isolated from *Pseudomonas* spp. showing the best performance (Yao *et al*., 2021). Fungal lipases have been used extensively in various biotechnology applications due to their stability, specificity, and ease of production. They include lipases isolated from *Thermomyces lanuginosus*, *Rhizopus oryzae,* and *Aspergillus niger,* all of which have important industrial applications. In yeast, lipases of the genus *Candida* have been used for the production of biodiesel and pharmaceuticals, as well as for research; these include lipases isolated from *Candida antarctica* and *Candida rugosa* (Sharma *et al*., 2016).

Structurally, microbial lipases are globular proteins (normally 20–60 kDa) that catalyze the hydrolysis of triglycerides into fatty acids and glycerol. Their three-dimensional (3D) design is structured as an alpha/beta Hydrolase Fold, the core architecture consisting of a central, mostly parallel beta-sheet flanked by alpha-helices. This offers the stable, rigid scaffold needed to house the catalytic machinery. The Catalytic Triad, which is the active site, is deeply buried and consists of a nucleophilic Serine (Ser), a Histidine (His), and an Aspartic/Glutamic acid (Asp/Glu). The consensus sequence surrounding the Serine residue is highly conserved as (Gly-x-Ser-x-Gly). The Oxyanion Hole, which is neighbouring the catalytic Serine. This feature stabilizes the developing negative charge on the substrate's oxygen atom during the enzymatic reaction. The "Lid": A mobile structural part comprising one or more (alpha-

https://dx.doi.org/10.4314/swj.v21i2.33

helices that covers the active site. It remains closed in aqueous environments and opens upon encountering a lipid-water interface, exposing the active site and thereby making the enzyme catalytically active. Metal Binding Sites, which require cofactors like (Ca^{2+} or Zn^{2+}) to maintain structural integrity, improve thermal stability, or assist in catalytic activity. Figure 1 shows the 3D structure of a typical microbial Lipase.

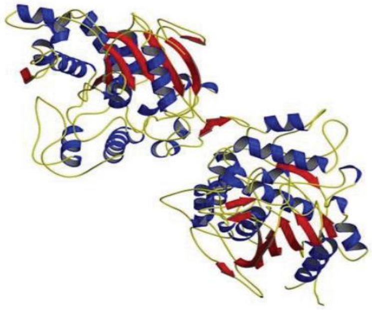

Figure 1: 3D Structure of Microbial lipase (Mala et al., 2008).

Microbial Lipase

Lipases are hydrolases (EC 3.1.1.3) that can break down lipid (triacylglycerols) to fatty acids and glycerol, and they can release monoglycerides, diglycerides, glycerol, and free fatty acids over an oil–water interface. It is also involved in the catalysis of transesterification and the hydrolysis of other esters. Lipases are universal enzymes of substantial physiological importance (Mahboob *et al*., 2022). Lipases constitute the third-largest family of digestive enzymes after proteases and carbohydrate-acting enzymes. They are an important group of biocatalysts in biotechnology. Lipases are highly diverse and ubiquitous, found in animals, plants, and microorganisms (Kumar *et al*., 2023). Lipases specially derived from microbial sources have gained increasing attention in the industrial fields rather than those that are derived from animals and plants due to their suitable characteristic features and functional ability under highly difficult conditions, and remain stable in organic solvents, chemical selectivity, and do not need any cofactor to increase their catalytic efficiency during reactions (Bharathi & Rajalakshmi, 2019; Thapa *et al*., 2019).

Microbial lipases are used more often than plant and animal lipases due to their high specificity across a broad range of substrates, ease of production, and adaptation to extreme environmental conditions such as high temperatures and pH values. They are often extracellular enzymes, which simplifies their recovery and purification process during industrial fermentation. Common lipase-producing microorganisms are Candida, Aspergillus, Rhizopus, Bacillus, Pseudomonas, and *Penicillium* spp.

Microbial lipase is indispensable in modern industry, offering eco-friendly, efficient, and cost-effective solutions across diverse sectors. Their broad specificity, high stability, and ability to catalyze reactions under mild conditions underscore their significance in promoting sustainable development and innovative industrial processes. As biotechnological advancements continue, the potential applications of lipases are expected to expand, further enhancing their role in shaping a more sustainable and environmentally conscious future (Sharma *et al*., 2025).

Sources of Microbial Lipase

Bacterial lipase

The significant bacterial genera are *Achromobacter*, *Alcaligenes*, *Arthrobacter*, *Bacillus*, *Burkholderia*, *Chromobacterium,* and *Pseudomonas*. Bacterial lipases depend on many parameters and on the nutritional environment, including carbon, lipids, inorganic salts, and nitrogen. The genera *Burkholderia* and *Pseudomonas* are the most commonly used bacteria for lipase production due to their high enzyme activity, low production cost, and ability to utilize waste substrate, thereby reducing waste disposal issues. Bacterial lipases are easy to produce in bulk due to their extracellular nature and are also commercially important (Mahboob *et al*., 2022). These enzymes are classified as glycoproteins and lipoproteins. The production of lipases in many bacterial species is influenced by specific polysaccharides (Abdelaziz *et al*., 2025). The lipases from these bacterial sources are not commonly used for food processing and are mainly used in detergent formulation and biodiesel production (Adetunji & Olaniran, 2021). Temperature is the primary factor influencing the growth and physiology of microbes used to produce desired products, such as lipases. Bacterial strains belonging to the genus *Exiguobacterium* can survive under harsh environmental conditions (12-55°C), and the lipases from *Exiguobacterium* function over a wide range of pH and temperatures, which makes them suitable for use in different industrial and agricultural processes. Similarly, lipases from *Pseudomonas glumae*, *Pseudomonas mendocina*, *Pseudomonas salcaligens*, *Pseudomonas fluorescens*, *Bacillus thermoscatenulatus*, and *Burkholderia cepacia* are used in the biofilm degradation, detergent, and biodiesel industries. Lipolytic bacteria are categorized into distinct families for lipase synthesis based on their genetic sequences, biochemical capabilities, and their habitats (Ali *et al*., 2023).

Fungal Lipase

Filamentous fungi are considered to be the best source of extracellular lipase for large-scale commercial production of all organisms used as a source of lipase. Due to their stability, selectivity, and broad substrate specificity, fungal lipases are of particular industrial interest (Gajera & Tarpara, 2023). Industrial waste, dairy plants, Vegetable oil processing factories, and oilseeds or contaminated soil are common sources of lipase-producing microorganisms. The highest lipolytic activity is observed in *Rhizome* species (Joshi & Kuila, 2018). In the industrial world, the most important fungal species that produce lipases are *Aspergillus* spp., *Penicillium* spp., *Rhizopus* spp., *Fusarium* spp., *Geotrichum* spp., *Trichoderma* spp., and *Mucor* spp. (Kumar *et al*., 2023). The production of lipases by fungi varies with fungal species, the composition of the growth medium, and physical conditions such as the nitrogen and carbon sources, pH, and temperature (Pandey *et al*., 2016). Fungi are widely regarded as one of the best lipase sources because of their substrate specificity and stability under various chemical and physical conditions. Lipases from fungal sources are predominantly extracellular and significantly reduce downstream processing costs, making this source preferable (Ali *et al*., 2023). Extracellular lipases are widely exploited because they can be easily separated from culture media and purified (Ali *et al*., 2023).

Yeast lipases

Yeast lipases are a very important source, given their unique attributes and ease of culture, making them sought after by many industries, including the pharmaceutical, chemical, and biodiesel industries. *Candida antarctica, Candida rugosa, Candida utilis*, and *Saccharomyces species* form the primary yeast producers of lipases, catalyzing a wide range of reactions and thus finding application in various industries (Sarmah *et al.,* 2017). *Candida antarctica* is another important yeast source of lipase, which is effectively used for the synthesis of valuable fatty acids, production of biodiesel through transesterification of *Simarouba glauca* oil, production of pharmaceutical products through acylation and alcoholysis, synthesis of cosmetic and detergent products by acidolysis of butter oil with conjugated linoleic acid, and acidolysis of acyl glycerols. The lipase from *Candida spp*. has been widely recognized for its structural, biochemical, and catalytic properties (Kumar *et al*., 2023).

Industrial and Environmental Applications of Lipases

Lipase in detergent industries

Lipase is used in detergents to improve their cleaning power. Because they are environmentally benign, effective at low temperatures, and do not lose their activity after stain removal (Abdelaziz *et al*., 2025), lipase-based detergents have better cleaning properties compared to synthetic detergents, as they are active at low temperatures, can be used in small quantities, do not lose their activity after removing stains, and are environmentally friendly (Ali *et al.,* 2023). Lipases added to detergent must be capable of functioning in a strongly alkaline environment, at high temperatures, and with various surfactants typically used in routine detergent preparations (Yao *et al*., 2021). This microbial lipase is now one of the most important enzymes used in detergents, as they soften fabrics and effectively removes stains that do not dissolve in water. Lipase is useful for breaking down greasy stains. They are environmentally safe as they leave no harmful residues and do not interfere with wastewater treatment or harm aquatic life (Sharma *et al.,* 2016). The lipases commonly used in the detergent industry include those from *Bacillus licheniformis*, *Geobacillus* spp., *Serratia marcescens* DEPTK21, *Bacillus flexus* XJU-1, *Bacillus pumilus* SG2, Staphylococcus arlettae, Bacillus cepacia, Pseudomonas fluorescens, and *Candida* spp. (Yao *et al*., 2021).

Food industry

Lipases have wide applications in biotechnology and in the production of numerous household products, especially in the food industry, where they enhance food quality, functionality, and nutritional value. Their main applications include flavour development and cheese ripening, as well as modifying lipid structures through transesterification or interesterification reactions to improve nutritional and sensory properties of food products (Kiran *et al*., 2016). The majority of enzymes used in industry are used in food processing, mainly for the modification and breakdown of biomaterials (Choudhury & Bhunia, 2015). Lipases from microorganisms such as *Mucor miehei*, *Aspergillus niger*, *Aspergillus oryzae,* and several others are used in the cheese manufacturing industry. They are also added to foods to enhance flavour by synthesizing esters from short-chain fatty acids and alcohols, which contribute to characteristic flavours and aromas (Choudhury & Bhunia, 2015). Lipases modify the properties of lipids by tailoring the location of fatty acid chains in glycerides, resulting in the conversion of a less desirable lipid into a high-value fat. Similarly, lipases catalyze the hydrolysis, esterification, and interesterification of oils and fats from various sources. Low-quality oils could be upgraded to synthesize nutritionally important low-calorie triacylglycerols (TAGs) (Ali *et al*., 2023). The dairy products sector uses lipases from *Pseudomonas* spp., *Bacillus* spp., *Penicillium* spp., *Rhizopus* spp., and *Mucor* spp. in various operations. Microbial lipases are frequently utilized for the hydrolysis of lipids in milk, which affects the length of the fatty acid chain, increases the flavour of cheese, and, in particular, aids in the development of soft cheese. Good-grade cheese has recently been produced using either a single microbial lipase or a mixture of lipases (Abdelaziz *et al.,* 2025). Microbial lipases are commonly used to enhance food quality by improving the flavour of rice, adding aroma to apple wine, and modifying soybean milk. Lipases are also utilized in biolipolysis to reduce fat in meat (Adetunji & Olaniran, 2021). Also, using lipase enzymes as biosensors in analytical and quantitative methods catalyzes the breakdown of triacylglycerol into glycerol, which can be measured to determine lipid content (Chandra *et al*., 2020).

Leather degreasing

In the leather industry, degreasing traditionally relies on solvents and emulsifiers, especially for sheepskins, but these chemicals generate harmful liquid waste that pollutes the environment. The introduction of the enzyme-based method has created a safer alternative for leather processing. Skin and hides contain moderate amounts of fat and grease, which are removed by lipase enzymes. Lipases hydrolyze triglycerides to glycerol and free fatty acids, and help in the isolation of collagen (Mahboob *et al.,* 2022). Lipases improve filling and dye penetration, giving the leather a uniform appearance (Ali *et al.,* 2023). The leather industry uses lipase to extract fat and collagen fibers from fur, making fur products softer and more flexible before tanning. Lipases break down lipids without damaging the leather and enable degreasing with lower environmental impact (Gajera & Tarpara, 2023).

Paper and pulp industry

Wood is processed to obtain paper and pulp. During this process, pitch is produced, which is a hydrophobic mixture of triglycerides and waxes. This pitch is undesirable because it jams the machine and degrades paper quality by producing holes and spots. Here, lipase plays an important role by breaking down 90% of the triglycerides present in the pitch into monoglycerides and fatty acids, which are less sticky and more easily washed with water (Shamim *et al*., 2018). In pulp and paper processing, resins and oils often contaminate pulp due to raw materials and machine components, leading to paper defects, equipment downtime, and reduced processing efficiency. Lipase enzymes can remove ester compounds from pulp, helping to reduce resin deposition and improve pulp quality and production efficiency. The addition of lipase can remove only the contaminating resins and oils in the paper; this will help reduce breakage and ensure paper quality and output (Almeida *et al*., 2018). Nippon, one of Japan's major paper industries, has developed a method to control contamination from wood pitch by affecting its hydrolysis (90%) using *C. rugosa* fungal lipase (Kumar *et al*., 2023).

Textile industry

In the textile industry, lipases are used alongside other enzymes during desizing (a crucial textile pretreatment process that removes sizing agents such as starch) to remove adhesive lubricants from warp threads, thereby improving fabric absorbency and uniform dyeing. In denim processing, lipases also help reduce cracks and streaks during abrasion. Commercially, lipases, in combination with alpha-amylase, are used for desizing cotton fabrics and denim (Kiran *et al.,* 2016). The use of lipases improves the dyeing performance of fabrics, with lower surface damage and weight loss. Microbial lipases from *Geobacillus* spp., *Pseudomonas* spp., *Candida* spp., *Aspergillus* spp., and *Streptomyces* spp. are routinely used in the textile industry (Ali *et al.,* 2023).

Cosmetics and personal care products production

Lipases have played a significant role in the cosmetic and personal care sectors, including softening, cleaning, aroma, and coloring. This sector has a considerable market value after the food and pharma sectors (Mehta *et al.,* 2017). Lipases have high potential for use in perfumery and cosmetics, as they exhibit activity in surfactants and aroma production (Mehta *et al*., 2017). The esterification of glycerol produces mono and diglycerol, which are used as surfactants in the cosmetics and perfume industries. Lipases catalyze the transesterification of 3,7-dimethyl-4,7-octadien-1-ol, producing rose oxide, a very important fragrance ingredient in the perfume industry. Moreover, Mouad *et al*. (2016) reported that immobilized Rhizomucor miehei lipase is used as a biocatalyst for the production of personal care products such as skin creams and bath oils. In addition, *Candida antarctica* B produces a lipase that synthesizes amphiphilic compounds that have attracted considerable attention in the cosmetic industry for their range of skin-beneficial properties.

Lipases in pesticides

A variety of pesticides (insecticides, herbicides, fungicides, or their precursors) containing lipases are currently in use. The most important application of lipases has been in the organic synthesis of pesticides to produce optically active compounds. Generally, these compounds were produced by resolving racemic mixtures of alcohols or carboxylic esters; stereospecific synthesis reactions were also employed. A highly stereospecific synthesis of the versatile chiral synthon possessing two stereogenic centres, which was subsequently converted into a homochiral intermediate for the synthesis of the biologically active potent pesticide nikkomycin-B. Use of *Achromobacter* lipase for enantioselective hydrolysis of the acetic acid ester of racemic a-cyano-3-phenoxybenzyl alcohol (CPBA) for the production of (S)-CPBA, an active insecticidal stereoisomer (Pogaku *et al*., 2017).

Biodiesel production

The production of biodiesel typically relies on animal fat and vegetable oil as biomass. Biodiesel is comprised of a fatty-acid monoester that is generated by transesterification of triglycerides from fats. At present, biodiesel is produced mainly by alkaline and supercritical fluid catalysis; lipase catalysis has been used in industrial biodiesel production (Yao *et al.,* 2021). Using the commercial lipase NovozymeR 435 (produced by Novozymes), edible waste oil was used as raw material to produce biodiesel via enzyme-catalyzed regeneration (Sorte *et al*., 2020). Similarly, Khosla et al. (2017) isolated an extracellular lipase from Pseudomonas ISTPL3; the lipid production of the liposophore ISTD04 was used for transesterification to produce biodiesel fuel. Enzymatic transesterification has many advantages over chemical transesterification, including the easy recovery of the byproduct glycerol in pure form, minimal waste generation, and lower energy consumption. Many studies have been reported in the literature on lipase-catalyzed biodiesel synthesis using various edible and non-edible oils. Although the raw materials for biodiesel production are abundant, the focus has been predominantly on non-edible oils to reduce competition with the food production sector. Several lipases are reported for biodiesel production, including the lipase from *Burkholderia cepacia* to catalyze the transesterification of castor oil, a non-edible oil (Sarmah *et al*., 2017).

Bioremediation

Bioremediation is the process used to decontaminate samples from oil spills, oil-wet soils, industrial wastes, and wastewater contaminated with lipids that can otherwise pose hazardous consequences when they enter natural resources without prior treatment. Lipase-catalyzed bioremediation steps can effectively treat waste from lipid-processing factories and restaurants. Lipase-producing organisms such as *Staphylococcus pasteuri* COM-4A, *Bacillus subtilis* COM-B6, and *Arthrobacter* spp. etc. have been reported to curb contaminants effectively. Lipases have been effectively applied in the bioremediation of contemporary problems associated with waste oil and pollution (Sarmah *et al.,* 2017). Enzyme-based bioremediation is an easily adjustable technique that removes these dangerous elements from our natural ecosystem in a more gentle manner than chemical or physical treatments. However, these enzymes' limited use in bioremediation stems from production challenges and exorbitant costs. As a result, the use of microbial enzymes for bioremediation is becoming increasingly significant globally. Furthermore, microbial enzymes are better able to convert pollutants into benign compounds and reduce pollution in the environment (Abdelaziz *et al.,* 2025).

Waste water or effluent treatment

Lipases play a key role in wastewater treatment through both aerobic and anaerobic processes. In aerobic systems, such as the activated sludge process, lipases help digest fats that accumulate on the surface of aerated tanks, allowing efficient oxygen transfer. Microorganisms such as Candida rugosa, Pseudomonas, Bacillus, and Acinetobacter produce lipases that degrade these fat-rich impurities. Anaerobic processes also utilize lipases to treat industrial and food waste, dairy effluents, wool grease, manure, and oil mill wastewater. Introducing lipase-producing bacteria into effluents further enhances treatment in industries such as food processing, tanneries, automotive, and restaurants. Lipases improve the efficiency of anaerobic digesters and can hydrolyze up to 90% of scum containing triglycerides, with immobilized lipase-producing bacteria offering even greater effectiveness. Proper enzymatic treatment can result in highly treated wastewater suitable for reuse, highlighting the essential role of microorganisms, which can be further optimized through genetic engineering (Sarmah *et al*., 2017).

Plastic Biodegradation

Lipases are increasingly recognized for their potential application in solving plastic pollution. It has been shown that lipases can hydrolyze PHA, polycaprolactone, and PCL. Interestingly, there is hope that these biodegradable plastics can be engineered into other synthetic polymers to make them more environmentally friendly (Sharma *et al.,* 2025). To mitigate environmental complications, biodegradable plastics are widely used as clean, green technologies, though some are used interchangeably despite their differences. The extent and rate of degradation are the main differences between biodestructible and biodegradable plastics, with the former requiring further management, whereas the latter do not. The biodegradability of plastics depends on the ability of lipases to degrade polycaprolactone (an aliphatic polyester). Lipase-producing species of bacteria applicable to the biodegradation of Polyurethanes (PUR) include *Pseudomonas protegens* BC2-12, *P. protegens* CHA0, *P. protegens* Pf-5, *P. fluorescens* A506 and Pf0-1, and *P. chlororaphis*. To act on PUR, one of the first enzymes identified was the PueB lipase from *Pseudomonas chlororaphis*. *Pseudomonas* spp. The genus of Gram-negative beta-proteobacteria has been most frequently linked to PUR activities. At least one additional enzyme active on PUR codes for an organism and is labelled as PueA; the secreted hydrolases degrade PUR, and the degradation is tightly regulated. From *Pseudomonas pelagia* (PpelaLip), a putative lipase recognized as a prospective enzyme performing on polyesters in a broad spectrum using an *in silico* genome mining approach. Polyurethane was degraded significantly by *Pseudomonas* spp. The production of high levels of extracellular lipases by Pseudomonas aeruginosa has been reported to facilitate the degradation of aromatic–aliphatic polyesters and polyester amides (Chandra *et al*., 2020).

Conclusion

Microbial lipases are versatile biocatalysts with profound industrial, biotechnological, and environmental applications. The microorganisms producing lipase are derived primarily from bacterial genera such as Bacillus, Pseudomonas, and Burkholderia, as well as fungal species such as Rhizopus, Aspergillus, and yeast-like Candida, enabling efficient production from various substrates, including agro-industrial wastes. Their broad substrate specificity, stability under extreme conditions, and ability to catalyze reactions like hydrolysis, esterification, and transesterification underpin transformative applications across sectors. They are useful in enhancing detergent efficacy at low temperatures and also high temperatures, improving food flavour, aroma, texture, and cheese ripening, degreasing leather without environmental harm, resolving pitch issues in paper production, refining textiles, synthesizing cosmetics and pesticides, producing sustainable biodiesel, facilitating bioremediation of oil spills and wastewater, and even degrading plastics like polyurethanes. Furthermore, advances in genetic engineering, enzyme immobilization, and process optimization continue to enhance lipase efficiency, stability, and application scope. Synthetic lipases are enzymes (or artificial biomimetic catalysts) designed or optimized to catalyze esterification, transesterification, and other synthetic reactions, rather than their natural function of breaking down fats. Unlike natural lipases that hydrolyze triglycerides, synthetic lipases are used in non-aqueous media to assemble complex molecules, such as biopolymers, biodiesel, and flavor esters. They function by reversing the hydrolysis process, linking fatty acids with alcohols (Scheibel *et al.,* 2024).

As global industries increasingly shift toward green technologies and sustainable processes, microbial lipases are expected to play an even more crucial role in addressing environmental challenges while supporting innovation and industrial development.

Acknowledgement:
The authors wish to acknowledge the management of Kaduna State University for providing an enabling ground for this work.

Declaration of Conflict

The authors declare no conflict of interest.

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