https://doi.org/10.31674/book.2022macbs.007

Current Perspective on Relevance and Applications of Microbial Enzymes in Industries: A Review

Baishali Pandit
Department of Botany, Surendranath College, Kolkata, West Bengal, India

Corresponding Author's Email: baishalipandit@gmail.com

ABSTRACT

Microorganisms' biocatalytic capacity has been used to make bread, wine, vinegar, and other familiar items for generations, although the biochemical foundation of their constituents is unknown. Microbial enzymes have gained appeal for their widespread application in industries and medicine due to their stability, catalytic activity, and ease of production procedures and optimization. Enzymes' usage in a variety of sectors (e.g., food, agriculture, chemicals, and medications) is fast rising due to its shorter processing time, low energy input, cost efficiency, nontoxic, and environmentally benign features. Toxic chemical substances in industrial and residential wastes (nitriles, amines, phenolic compounds and so on) can also be degraded or transformed by microbial enzymes.

Keywords: *Biocatalysts; Microorganisms; Enzymes; Industries; Non-Toxic; Eco-Friendly*

INTRODUCTION

Enzymes are biological substances or biological macromolecules generated by living organisms that serve as a catalyst for a certain biochemical process. These operate as chemical catalysts in chemical processes, speeding up biological and biochemical reactions both within and outside the cell. Natural enzymes have been employed in the production of items such as linen, leather, and indigo since ancient times. The invention of fermentation techniques was primarily focused at the manufacture of enzymes using specially chosen strains, allowing for the large-scale production of pure, well-characterized enzymes. This breakthrough allowed enzymes to be integrated into real commercial goods and processes, such as in the detergent, textile, and starch sectors. Recombinant DNA technology has helped to enhance manufacturing processes and commercialize enzymes that were previously unavailable (Le Roes-Hill & Prins, 2016). Furthermore, technological advances such as protein engineering and guided evolution altered the marketing of industrially significant enzymes. This advancement in biotechnology is resulting in the development of novel enzymes with new activity and adaptability to new environments, resulting in their increased usage in industrial applications. As a result, enzymes have a wide variety of uses in several sectors, including food, textiles, medicine, dairy, and others. The competence of the genes can be changed to make these new enzymes applying contemporary biotechnology and protein engineering. The goal of this study is to highlight the existing function of microbial enzymes, as well as the current state of their utilization in many sectors and biotechnological potential for future development. Industrial, pharmaceutical and biotechnological processes all rely heavily on enzymes procured from microbial sources. They are profusely used in industries like detergents, textiles, pulp and paper, biofuels and others.

LITERATURE REVIEW

Textile industry

Enzymes are being used more and more in the textile industry to create cleaner processes and reduce raw material consumption and waste generation (Araujo, Casal & Cavaco-Paulo, 2008). Reducing starch size, dissolving glue between the fibre core and the waxes, finishing denims, decomposing residue hydrogen peroxide after cotton bleaching, wool treatment, and biopolishing may all be done with enzymes including cellulase, amylase, catalase, pectinase, and protease (Aiyer, 2005).

Table 1: Some enzymes used in textile industry with their sources and applications

Enzyme	Source	Applications
Catalase	*Aspergillus sp.*	Bleach termination
Pectate lyase	*Bacillus sp., Pseudomonas sp*	Bioscouring
Cellulase	*Aspergillus niger, Penicillium funiculosum*	Softening of cotton, finishing of denim
Lipase	*Candida antarctica*	Denim processing
Amylase	*Bacillus licheniformis* and other *Bacillus sp.*	Desizing
Laccase	*Bacillus subtilis*	Dyeing and bleaching of fabric
Protease	*Aspergillus niger, Bacillus subtilis*	Processing of wool and silk
Cutinase	*Thermomonospora fusca, Pseudomonas mendocina, Fusarium solani pisi*	Processing of cotton fiber
Ligninase	*Trametes versicolor, Phlebia radiata*	Wool processing
Collagenase	*Clostridium histolyticum*	Wool processing

Feed Industry

Cellulases are low-cost lignocellulosic biomass conversion systems which can further be utilized for generation of biofuels and other products (Choct, 2006). Cellulases and hemicellulases from *Trichoderma reesei* and *Caldicelluloseruptor bescil* efficiently degrade the complex carbohydrates of plants into simple sugars. Feed enzymes improve nutrient digestibility and breakdown undesirable feed components (Kanafusa-Shinkai *et al.*, 2013). Galactosidases, phytases, glucanases, proteases, polygalacturonases, amylases and xylanases are important feed enzymes.

Food Processing

Fungal amylase, lipase, invertase, glucose isomerase, glucoamylase, all are utilised in vegetable fermentations, fruit juices, dairy enrichment, candy, baked goods and jam production (Aravindan, Anbumathi & Viruthagiri, 2007; Aruna, Shah & Birmole, 2014; Camacho & Aguilar, 2003; Grassin & Fauquembergue, 1996; Jooyendeh, Amarjeet & Minhas, 2009; Law, 2009, Al-Maqtari, Waleed & Mahdi, 2019, Panda & Gowrishankar, 2005; Zhu *et al.*, 2017). The FDA has authorised four recombinant proteases for use in cheese manufacturing. Fructose syrup is generated by xylose isomerase. Food additives such as lysozyme and invertase are used. *Bacillus subtilis, Bacillus licheniformis, Aspergillus oryzae* and *Aspergillus niger* are approved by FDA as "Generally Recognized As Safe" (GRAS) for food processing. Amylases, glucanases, arabinoxylans, proteases, beta-glucanases, pullulanases, amyloglucosidase, and acetolactate decarboxylase are used in the production of alcoholic beverages (Blanco *et al.*, 2014; Choi, Ahn & Kim, 2015; Seo *et al.,* 2016).

Table 2: Some enzymes used in food processing with their sources and applications

Enzymes	Sources	Industrial Applications	Functions
Protease	*Aspergillus usamii, Aspergillus niger, Bacillus subtilis Aspergillus flavus, Alcaligenes faecalis, Chrysosporium keratinophilum*	Brewing Tenderization of meat Milk coagulation Enhanced bread quality	Restrict haze formation in beverage industry
α-Amylase	*Bacillus amyloliquefaciens, Bacillus stearothermophilus, Bacillus licheniformis, Streptomyces, Rhizopus*	Baking, brewing, starch liquefaction, Bread quality improvement, Clarification of fruit juice	Flour adjustment, bread softness in baking. Starch hydrolysis in beverage industry
Glucoamylase	*Aspergillus niger, Aspergillus awamori, Rhizopus oryzae*	Beer production Manufacture of glucose and fructose syrups	
Lactase (β-galactosidase)	*Kluyveromyces lactis, Kluyveromyces fragilis*	Used to reduce Lactose intolerance, Ingredients of Prebiotic food	
Lipase	*Aspergillus niger, A. oryzae, Penicillium camemberti, Rhizopus miehei, Candida antarctica, Candida cylindracea Ay30, Candida rugosa, Pseudomonas sp., Helvina lanuginosa, Geotrichum candidum*	Cheese flavour development, Cheddar cheese production	
Phospholipase	*Fusarium oxysporum*, *Bacillus licheniformis*	Development of flavour of cheese, lipolyzed milk fat production	
Esterase	*Lasiodiplodia theobromae*	Flavour and fragrance augmentation in fruit juice, De-esterification of dietary fibre.	
Cellulase	*Aspergillus sp., Trichoderma sp., Bacillus sp., Paenibacillus sp.*	Enhancement of flavour of fruit juice	
Pectinase		Enhancement of flavour of fruit juice	
Glucose oxidase	*Aspergillus niger, Penicillium glaucum, Aspergillus niger, Penicillium adametzii.*	Increase in shelf life of food, enhancement of flavour of food	
Laccase	*Funalia trogii, Bacillus licheniformis*	Removal of polyphenol from wine, used in baking	
Xylanase	*Streptomyces sp., Bacillus sp., Pseudomonas sp. Aspergillus sp., Fusarium sp., Penicillium sp.*	Enhancement of flavour of fruit juice, Enhancement of quality of Beer	

Peroxidase	*Phanerochaete chrysosporium, Streptomyces viridosporus T7A*	Food flavour, colour, and nutritional quality enhancement	
α-Acetolactate dehydrogenase	*Brevibacillus brevis*	Beer maturation and shortening	
Asparaginase		During baking, the generation of acrylamide is reduced.	
Debittering enzymes - naringinase	*Penicillium, Rhizopus, Circinella, Trichoderma, Fusarium, Aspergillus niger, Eurotium, Bacteriodes distasonis, Bacillus sp., Thermomicrobium roseum, Burkholderia cenocepacia, Pseudomonas paucimobilis.*	Enhancement of wine scent and removal of bitter flavour in fruit juice	
Catalase	*Bacteroides fragilis, Enterococcus faecalis, Bacillus maroccanus, Pyrobaculum calidifontis*	Preservation of food, Employed in production of cheese for hydrogen peroxide removal from milk	

Pulp and paper industry

The use of microbial enzymes in this industry decreases processing time, energy usage, and chemical use (Fu, Chan & Minns, 2005). Xylanase, ligninase, laccase, mannase, amylase, lipase, cellulase, hemicellulase, and esterase breakdown starch to reduce viscosity, making it easier to size, deink, and coat paper (Farrell, Hata & Wall, 1997; Gutiérrez, Del Río & Martínez, 2009; Pasha, Anuradha & Subbarao, 2013; Patrick, 2004; Srivastava & Singh, 2015). Lipases lower pitch, lignin-degrading enzymes remove lignin to soften paper for esterification and cellulases and hemicellulases aid in water drainage, fibre smoothing, and ink removal.

Table 3: Some enzymes used in pulp and paper industry with their sources and applications

Enzyme	Source	Applications
Laccase	*Bacillus subtilis*	Non-chlorine bleaching, delignification
Protease	*Bacillus subtilis*	Biofilm removal
Amylase	*Bacillus licheniformis*	Deinking, drainage improvement
Lipase	*Candida antarctica*	Pitch control
Mannase		Degrades glucomannan to improve brightness in paper
Ligninases		Removal of lignin and hemicellulose
Xylanase	*Aureobasidium pullulans, Trichoderma reesei, Thermomyces lanuginosus,*	Improvement of Bleaching
Cellulase	*Bacillus sp., Aspergillus niger*	Deinking, drainage improvement

Polymer industry

The ecologically friendly in vitro microbial enzyme catalyses production of biodegradable polymer and has various benefits over traditional chemical techniques. Biopolymers are ecologically benign materials, made from renewable carbon sources and decompose after use into renewable nutrient resources to be recycled in the environment again. To synthesise materials in situ via polymerization processes, peroxidases, transglutaminases, lipases, and laccases tend to produce cross-links in biopolymers (Lang & Cotteret, 2004; Vroman & Tighzert, 2009).

Table 4: Some enzymes used in polymer industry with their sources and applications

Enzyme	Source	Applications
Glucose oxidase	*Aspergillus niger, Penicillium chrysogenum*	Polymerization of anilines
Lipase	*Candida antarctica*	lactone polycondensation and polymerization (ring opening), carbonates
Transglutaminase	*Streptomyces mobaraensis*	Crosslinking of protein
Tyrosinase	*Trichoderma reesei*	lignin and chitosan polymerization
Laccase	*Trametes hirsuta*	Bisphenol polymerization

Detergent industry

Microbial enzymes such as lipase, protease, cellulase, amylase, mannanase and peroxidase are added to detergents to catalyse chemical bond breakdown under high temperature (60°C) and highly alkaline (pH 9–11) conditions. These enzymes help remove protein stains, insoluble starch in dishwashing, oils and fats, and they also help detergents work better (Hasan *et al.*, 2010; Keshwani, Malhotra & Kharkwal, 2015).

Table 5: Some enzymes used in detergent industry with their sources and applications

Enzyme	Source	Applications
Protease	*Aspergillus oryzae, Bacillus subtilis*	Protein stain removal
Amylase	*Aspergillus sp., Bacillus subtilis*	Carbohydrate stain removal
Cellulase	*Aspergillus niger, Bacillus sp.*	Colour clarification
Lipase	*Aspergillus oryzae, Aspergillus flavus*	Fat stain elimination
Mannanase	*Bacillus sp.*	Mannan spot removal
Cutinase	*Fusarium solani f. pisi*	Triglyceride removal

Leather industry

The use of enzymes as chemical alternatives in leather manufacturing has been shown to improve leather quality while also lowering pollution (De-Souza & Gutterres, 2012; Money, 1996). In this industry, alkaline lipases from *Bacillus* strains that thrive in very alkaline conditions are employed in conjunction with other alkaline or neutral proteases (Choudhary, Jana & Jha, 2004).

Table 6: Some enzymes used in leather industry with their sources and applications

Enzyme	Source	Applications
Amylase	*Aspergillus sp., Bacillus subtilis*	Fiber splitting
Alkaline protease	*Alcaligenes faecalis*	Removal of hair, bating
Neutral Protease	*Bacillus subtilis, Aspergillus niger, Aspergillus flavus*	Removal of hair, soaking
Lipase	*Aspergillus oryzae, Aspergillus flavus*	Removal of grease

Cosmetic industry

Retinoids (vitamin A and derivatives) are widely used in cosmetics and medications, including skin care products. The manufacture of water-soluble retinol derivatives is accomplished with immobilised lipases (Cho, Cho & Han, 2007). Lipases are employed in the creation of hair waves and have also been utilised as components in topical anti-obesity treatments or as an oral administration (Babizhayev, 2006).

Table 7: Some enzymes used in cosmetic industry with their sources and applications

Enzyme	Source	Applications
Endoglycosidase	*Mucor hiemalis*	Teeth and gum tissue care
Superoxide dismutase	*Corynebacterium glutamicum, Lactobacillus plantarum*	Free radical scavenging, skin care
Laccase	*Bacillus subtilis, Trametes versicolor*	Hair dye
Protease	*Bacillus subtilis, Aspergillus flavus, Aspergillus niger*	Removal of dead skin
Lipase	*Aspergillus flavus, Aspergillus oryzae*	Skin care

Waste management

Enzymes are widely used in management of waste, and a multitude of enzymes are involved in the breakdown of harmful substances found in industrial effluents and household garbage. Amyloglucosidases, amylases, amidases, glucoamylases, cellulases, lipases, pectinases, nitrile hydratases and proteases are some of the enzymes used in waste treatment (Kuhad, Gupta & Singh, 2011). They are used to encourage the removal of hazardous compounds from industrial effluents as well as the recycling and reuse of garbage (Masse, Kennedy & Chou, 2001).

Table 8: Some enzymes used in waste management with their sources and applications

Enzyme	Source	Applications
Amyloglucosidase	*Aspergillus niger*	Hydrolysis of starch for bioremediation
Amidase	*Rhodococcus erythropolis*	Wastes containing nitriles are degraded.
Cutinase	*Fusarium solani f. pisi*	Plastic degradation, Polycaprolactone
Amylase	*Bacillus licheniformis, Aspergillus sp*	Vegetable waste bioremediation
Lipase	*Aspergillus oryzae, Candida tropicalis*	Hydrocarbons from crude oil are degraded.
Protease	*Chrysosporium keratinophilum*	Keratinic waste bioremediation
Manganese peroxidase	*Phanerochaete chrysosporium, Coprinus cinereus*	Phenolic molecules are degraded.
Laccase	*Trametes versicolor*	Waste comprising olefin units, polyurethane, and phenolic chemicals is degraded.
Oxygenase	*Pseudomonas sp., Rhodococcus sp.*	Halogenated pollutants are degraded.
Nitrile hydratase	*Rhodococcus sp.*	Wastes containing nitriles are degraded.
Lignin peroxidase	*Phanerochaete chrysosporium, Coprinus cinereus*	Phenolic molecules are degraded.

Therapeutic applications of microbial enzymes

Anticoagulants, oncolytics and thrombolytics are only a few of the applications for therapeutic enzymes, as well as substitutes for metabolic deficits (Kaur & Sekhon, 2012; Mane & Tale, 2015). Proteolytic enzymes have anti-inflammatory properties.

Table 9: Some enzymes used as therapeutic agents with their sources and applications

Applications	Source	Enzymes
Antibiotic synthesis	*Penicillium sp.*	Penicillin oxidase, rifamycin B oxidase
Antitumor	*Pseudomonas acidovorans, Escherichia coli, Acinetobacter, Beauveria bassiana*	L-tyrosinase, L-Asparaginase, galactosidase L-glutaminase
Antioxidants	*Lactobacillus plantarum, Corynebacterium glutamicum*	Superoxide dismutases, glutathione peroxidases, catalase
Anticoagulants	*Streptococcus sp., Bacillus subtilis*	Streptokinase, urokinase
Anti-inflammatory	*Mycobacterium sp., Lactobacillus plantarum, Corynebacterium glutamicum, Nocardia sp.*	Superoxide dismutase, Serrapeptase
Antiviral	*Saccharomyces cerevisiae*	Ribonuclease, Serrapeptase
Resistance to Antibiotics	*Citrobacter freundii, Klebsiella pneumonia, Serratia marcescens*	Lactamase
Skin ulcers	*Clostridium perfringens*	Collagenase
Detoxification	*Pseudomonas aeruginosa*	Laccase, rhodanese
Cyanide poisoning	*Sulfobacillus sibiricus*	Rhodanase
Digestive disorders	*Candida lipolytica, Bacillus spp., Aspergillus oryzae*	Amylase, lipase
Gout	*Aspergillus flavus*	Uricase

Application in molecular biology

DNA ligases, restriction enzymes, and polymerases are used in genetic engineering to alter DNA for restriction digestion and polymerase chain reactions. In addition, they can be employed in forensic science (Le Roes-Hill & Prins, 2016).

DISCUSSION

Industry-produced microbial enzymes are derived from a variety of microorganisms, including bacteria, fungus, and yeasts (Kirk, Borchert & Fuglsang, 2002). Enzymes made in factories with the aid of microbes were discovered to have high biological activity. Enzymes are cost-effective and can be generated in big quantities (Gurung *et al.*, 2013; Singh *et al.*, 2016; Zhang, 2011). In compared to plant and animal sources, the isolation and purification of enzymes from microbial sources is easier. Microbial sources can produce a wide range of enzymes under a variety of environmental circumstances in a short amount of time and space. To increase the number of enzymes generated by microbial sources, genetic modification is used (Adrio & Demain, 2014). Traditional means to Reducing starch size, dissolving glue between the fibre core and the waxes, finishing denims, decomposing residue hydrogen peroxide membrane filtering techniques combined with downstream processing. Thus, industries are keenly interested in employing enzymes for making the procedure less complex, energy saving and moreover to keep the environment pollution free.

CONCLUSION

Microbial enzymes may be used to clean water sanitization systems, for decontamination of effluents from petrochemical industries, paper and pulp industry, food, detergent, pharmaceutical, and paper sectors textiles, for bioremediation of herbicides, as a medical diagnostic tool, as a cleaning agent for water purification systems, as cosmetic constituents, as a catalytic agent in drug manufacturing and as pesticides. Because of their environmentally benign nature, effective procedure regulation, little purifying expenses, high yield, and process safety, enzymatic hydrolysis and enzyme-based technologies are now favoured over chemical processes.

Different fermentation processes, such as solid-state and submerged fermentations, can manufacture microbial enzymes more effectively than plant and animal enzymes. It is also simple to mass-produce microbial enzymes. Various molecular and biological techniques can be used to modify microbial enzymes. Overexpression of microbial enzyme genes can result in hyperproduction of enzymes with high specific activity. Many microbial enzymes are still to be discovered, and there are numerous prospects for developing greater commercial applications of microbial enzymes, for most of the industries.

ACKNOWLEDGMENT

The author expresses her deep sense of gratitude to Dr. Indranil Kar, principal, Surendranath College for his constant support and encouragement in writing this article. She is equally grateful to Department of Botany, Surendranath College for providing her the latest information on this area.

REFERENCES

Adrio, J. L., & Demain, A. L. (2014). Microbial enzymes: tools for biotechnological processes. *Biomolecules, 4*(1), 117-139. https://doi.org/10.3390/biom4010117

Aiyer, P. V. (2005). Amylases and their applications. *African Journal of Biotechnology, 4*(13).

Al-Maqtari, Q. A., Waleed, A. A., & Mahdi, A. A. (2019). Microbial enzymes produced by fermentation and their applications in the food industry-A review. *International Journal of Agriculture Innovations and Research, 8*(1), 2319-1473.

Araujo, R., Casal, M., & Cavaco-Paulo, A. (2008). Application of enzymes for textiles fibers processing. Biocatal Biotechnol 26: 332–349.

Aravindan, R., Anbumathi, P., & Viruthagiri, T. (2007). Lipase applications in food industry. *Indian J Biotechnol., 6*, 141-58.

Aruna, K., Shah, J., & Birmole, R. (2014). Production and partial characterization of alkaline protease from Bacillus tequilensis strains CSGAB0139 isolated from spoilt cottage cheese. *Int J Appl Biol Pharm, 5*, 201-221.

Babizhayev, M. A. (2006). Biological activities of the natural imidazole-containing peptidomimetics n-acetylcarnosine, carcinine and L-carnosine in ophthalmic and skin care products. *Life Sciences, 78*(20), 2343-2357.

Blanco, C. A., Caballero, I., Barrios, R., & Rojas, A. (2014). Innovations in the brewing industry: Light beer. *International Journal of Food Sciences and Nutrition, 65*(6), 655-660. https://doi.org/10.3109/09637486.2014.893285

Camacho, N. A., & Aguilar O, G. (2003). Production, purification, and characterization of a low-molecular-mass xylanase from Aspergillus sp. and its application in baking. *Applied Biochemistry and Biotechnology, 104*(3), 159-171. https://doi.org/10.1385/ABAB:104:3:159

Cho, S. A., Cho, J. C., & Han, S. H. (2007). Cosmetic composition containing enzyme and amino acid. *U.S. Patent Application No. 13/410,428*.

Choct, M. (2006). Enzymes for the feed industry: past, present and future. *World's Poultry Science Journal, 62*(1), 5-16.

Choi, E. J., Ahn, H. W., & Kim, W. J. (2015). Effect of α-acetolactate decarboxylase on diacetyl content of beer. *Food Science and Biotechnology, 24*(4), 1373-1380. https://doi.org/10.1007/s10068-015-0176-y

Choudhary, R. B., Jana, A. K., & Jha, M. K. (2004). Enzyme technology applications in leather processing. *Ind J Chem Technol, 11*, 659–671.

De Souza, F. R., & Gutterres, M. (2012). Application of enzymes in leather processing: a comparison between chemical and coenzymatic processes. *Brazilian Journal of Chemical Engineering, 29*(3), 473-482.

Farrell, R. L., Hata, K., & Wall, M. B. (1997). Solving pitch problems in pulp and paper processes by the use of enzymes or fungi. In *Biotechnology in the Pulp and Paper Industry* (pp. 197-212). Springer, Berlin, Heidelberg.

Fu, G. Z., Chan, A., & Minns, D. (2005). Preliminary assessment of the environmental benefits of enzyme bleaching for pulp and paper making (7 pp). *The International Journal of Life Cycle Assessment, 10*(2), 136.

Grassin, C. A. F. P., & Fauquembergue, P. (1996). *Fruit juices. Industrial Enzymology, 2*, 225-264.

Gurung, N., Ray, S., Bose, S., & Rai, V. (2013). A broader view: microbial enzymes and their relevance in industries, medicine, and beyond. *BioMed Research International, 2013*. https://doi.org/10.1155/2013/ 329121

Gutiérrez, A., Del Río, J. C., & Martínez, A. T. (2009). Microbial and enzymatic control of pitch in the pulp and paper industry. *Applied Microbiology and Biotechnology, 82*(6), 1005-1018.

Hasan, F., Shah, A. A., Javed, S., & Hameed, A. (2010). Enzymes used in detergents: lipases. *African Journal of Biotechnology, 9*(31), 4836-4844. https://doi.org/10.5897/AJBx09.026

Jooyandeh, H., Amarjeet, K., & Minhas, K. S. (2009). Lipases in dairy industry: A review. *Journal of Food Science and Technology (Mysore), 46*(3), 181-189.

Kanafusa-Shinkai, S., Wakayama, J. I., Tsukamoto, K., Hayashi, N., Miyazaki, Y., Ohmori, H., ... & Yokoyama, H. (2013). Degradation of microcrystalline cellulose and non-pretreated plant biomass by a cell-free extracellular cellulase/hemicellulase system from the extreme thermophilic bacterium Caldicellulosiruptor bescii. *Journal of Bioscience and Bioengineering, 115*(1), 64-70.

Kaur, R., & Sekhon, B. S. (2012). Enzymes as drugs: an overview. *Journal of Pharmaceutical Education & Research, 3*(2).

Keshwani, A., Malhotra, B., & Kharkwal, H. (2015). Natural polymer based detergents for stain removal. *World J Pharm Pharm Sci, 4*(4), 490-508.

Kirk, O., Borchert, T. V., & Fuglsang, C. C. (2002). Industrial enzyme applications. *Current Opinion in Biotechnology, 13*(4), 345-351.

Kuhad, R. C., Gupta, R., & Singh, A. (2011). Microbial cellulases and their industrial applications. *Enzyme Research, 2011*. https://doi.org/10.4061/2011/280696

Lang, G, & Cotteret, J. (2004). Composition for the oxidation dyeing of keratinous fibres containing a laccase and dyeing method using this composition. US2004255401 A1

Law, B. A. (2009). Enzymes in dairy product manufacture. *Enzymes in Food Technology*, 92-93. https://doi.org/10.1002/9781444309935.ch5

Le Roes-Hill, M., & Prins, A. (2016). Biotechnological potential of oxidative enzymes from Actinobacteria. *Actinobacteria-Basics and Biotechnological Applications*, 200-226. https://doi.org/10.5772/61321

Mane, P., & Tale, V. (2015). Overview of microbial therapeutic enzymes. *Int J Curr Microbiol App Sci, 4*(4), 17-26.

Masse, L., Kennedy, K. J., & Chou, S. (2001). Testing of alkaline and enzymatic hydrolysis pretreatments for fat particles in slaughterhouse wastewater. *Bioresource Technology, 77*(2), 145-155.

Money, C. A. (1996). Unhairing and dewooling-requirement for quality and the environment. J Soc Leather Tech Chem, 80, 175–186.

Panda, T., & Gowrishankar, B. S. (2005). Production and applications of esterases. *Applied Microbiology and Biotechnology, 67*(2), 160-169. https://doi.org/10.1007/s00253-004-1840-y

Pasha, K. M., Anuradha, P., & Subbarao, D. (2013). Applications of pectinases in industrial sector. *International Journal of Pure and Applied Sciences and Technology, 16*(1), 89.

Patrick, K. (2004). Enzyme technology improves efficiency, cost, safety of stickies removal program. Paper Age, 120, 22-25.

Seo, Y. B., Park, J., Huh, I. Y., Hong, S. K., & Chang, Y. K. (2016). Agarose hydrolysis by two-stage enzymatic process and bioethanol production from the hydrolysate. *Process Biochemistry, 51*(6), 759-764.

Singh, R., Kumar, M., Mittal, A., & Mehta, P. K. (2016). Microbial enzymes: industrial progress in 21st century. *3 Biotech, 6*(2), 1-15.

Srivastava, N., & Singh, P. (2015). Degradation of toxic pollutants from pulp & paper mill effluent. *Discovery, 40*(183), 221-227.

Vroman, I., & Tighzert, L. (2009). Biodegradable polymers. *Materials, 2*(2), 307-344.

Zhang, Y. H. P. (2011). What is vital (and not vital) to advance economically-competitive biofuels production. *Process Biochemistry, 46*(11), 2091-2110.

Zhu, Y., Jia, H., Xi, M., Li, J., Yang, L., & Li, X. (2017). Characterization of a naringinase from Aspergillus oryzae 11250 and its application in the debitterization of orange juice. *Process Biochemistry, 62*, 114-121.https://doi.org/10.1016/j.procbio.2017.07.012