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Microbial lipases: An overview of screening, production and purification

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ABSTRACT

Lipases are industrially important biocatalyst, particularly microbial lipases and therefore, screening, production and purification of lipase enzyme from microbial strains are continuously emerging to fulfil the needs of pharmaceutical and food industries. More recently, various cost effective and efficient approaches are being attempted to increase the production of lipases in microbial strains. In this junction, this article attempt to connect production of lipases using various microbial strains such as bacteria, fungi and yeast has been highlighted and discussed, in order to enable researchers to choose an appropriate strains for lipase production. Then, screening of lipase producer and production of lipases under different fermentation system was discussed. Later, impact of various factors such as carbon sources, nitrogen sources, pH and temperature has been assessed, and presented in the perspective of increasing its production from microbial strains. Finally, purification techniques for lipase enzymes was summarized and recent literature pertaining to lipase purification from microbial stains are reviewed, and summarized.

1. Introduction

Lipases (triacylglycerol acylhydrolases; EC 3.1.1.3) are class of hydrolytic enzymes which catalyze the hydrolysis of insoluble triacylglycerol to glycerol, acylglycerols, and free fatty acids (Andualema and Gessesse, 2012; Akil et al., 2016; Geoffry and Achur, 2017). Lipases are a subclass of esterases and have long chain triacyl-glycerols, which is very low soluble in water and the reaction is catalysed at lipid-water interface (Aulakh and Prakash, 2010; Kumar and Kanwar, 2012). Lipases are highly efficient in the catalysing reactions in both aqueous and non-aqueous media due to their high stability in extremes of temperature, pH and organic solvents (Tan et al., 2018). Lipases are known to contain a hydrophobic lid, which is necessary for its interfacial activity (Khan et al., 2017).

Lipases are classified into two different categories based on the specificity and sources. Schematic representation of lipase classification has been shown in Fig. 1. Lipases have been found in many species of plants, animals, insects and microorganisms (Sahu and Martin, 2011; Sarmah et al., 2018). Lipases are extremely different in character and are ubiquitous in plants, animals and microorganisms (Zheng, 2018). The lipases, especially microbial lipase have gained much attention industrially than those derived from plants and animals due to their desirable characteristics and functional ability at extreme conditions, stability in organic solvent, chemo-selectivity, enantio-selectivity and they do not require any co-factor (Thapa et al., 2019; Ramyasree and Dutta, 2013).

The high versatility of lipases, recognized as the most important group of biocatalysts in biotechnology field, which allows their applications in different industries like food, detergent, pharmaceutical, leather, textile, cosmetic, bio diesel production and paper industries (Kaur et al., 2016; Mouad et al., 2016; Avhad and Marchetti, 2019). The ability of lipases to perform very specific chemical and biological transformation has make them increasingly popular in those industries (De Abreu et al., 2014; Joseph et al., 2011; Maiangwa et al., 2015). Current review is investigated on microbial lipases, exploring the main methodologies used in screening and production process, enumerating influences of physical and chemical factors as well as purification techniques for these microbial lipases was discussed.

2. Microbial production of lipases

Among various lipases, microbial lipases have gained superior industrial attention due to their selectivity, stability, and broad substrate specificity (Treichel et al., 2010; Kumar et al., 2016). Many microorganisms are known as potential producers of lipases, including bacteria, fungi and yeast.

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2.1. Bacterial lipases

Many different Gram-positive and Gram-negative bacterial strains produce lipase enzyme. Some of the most commercially important lipase producing bacteria are recognized as belonging to the genera of *Bacillus*, which includes *Bacillus subtilis*, *Bacillus licheniformis*, *Bacillus pumilus*, *Bacillus alcalophilus*, *Bacillus coagulans, Bacillus stearothermophilus* and also some other bacterial strains such as *pseudomonas* sp., *Burkholderia* sp. and *Staphylococcus* sp. are also reported as better bacterial lipase producer (Suci et al., 2018; Sangeetha et al., 2010; Mabizela-Mokoena et al., 2017; Gowthami et al., 2015; Dror et al., 2015; Daoud et al., 2013). Lipase-producing bacterial strains has been found in different habitats such as oil industrial wastes, vegetable oil processing factories, dairy plants, paper industries and soil contaminated with oils. Tripathi et al. (2014) isolated eight different lipase producing bacteria from the pulp and paper mill industries. Recently, Bharathi et al. (2018) isolated five different lipase producing bacterial strains from petrol spilled soil. A review of the most recent potential bacterial strains for lipase production and their isolation area was reported in Table 1. According to the previous literature reports, oil contaminated sites are preferable for isolation of lipase producing bacterial strains. Furthermore, being nontoxic and eco-friendly, lipase are considered more suitable as compared to other chemical or synthetic catalysts. Therefore, widely used in food, dairy, flavour, detergent, pharmaceuticals, biofuels and cosmetics industries (Javed et al., 2018).

2.2. Fungal lipases

Fungal strains are known to be potential lipase producers with notable unique catalytic properties which are very important to various commercial applications (Pandey et al., 2016). Most of the commercially and industrially important lipase-producing fungi belong to the genera of *Rhizopus* sp., *Aspergillus* sp., *Penicillium* sp., *Geotrichum* sp., *Mucor* sp. (Riyadi et al., 2017; Oliveira et al., 2016; Pandey et al., 2016; Maldonado et al., 2016; Ülker and Karaoğlu, 2012). Lipase production by fungus varies according to the strain and composition of the growth medium such as carbon and nitrogen sources (Pandey et al., 2016).

Among microbial sources, filamentous fungus are good lipase producers and the extraction, purification, and processing steps are relatively simple. Roy et al. (2018) isolated a strain of *Aspergillus aculeatus* from dairy waste contaminated soil and they obtained an expressive lipase producing activity of 9.51 U/ml.

The industrial demand for new sources of lipases with different catalytic character stimulates the isolation and selection of new fungal strains. Various lipase producing fungal strains are isolated by Colen et al. (2006) from Brazilian savanna soil by using enrichment culture techniques. A general view of the lipases from fungal sources and their isolation area are given in Table 1.

2.3. Yeast lipases

Lipase produced from yeast has unique applications in chemical, pharmaceutical and biodiesel producing industries (Singh and Mukhopadhyay, 2012). Recent literature survey shows, *Candida utilis*, *Candida rugosa*, *Rhodotorula* sp., *Yerrowia* sp. and *Pichia* sp. are the best and primary lipase producers (Moftah et al., 2012; Su et al., 2016; Divya and Padma, 2015; Lan et al., 2016; Fang et al., 2014; Resina et al., 2009). As per literature reports, *Candida* sp. is the most potential lipase producer from yeasts category. Biochemical, structural, and catalytic properties of *Candida* sp. lipase have been widely documented. He and Ten, (2006) investigated the production of lipase enzyme by *Candida* sp. and obtained an activity of 9.600 U/mL. Rajendran et al. (2008) documented the optimum lipase activity of 3.8 U/mL produced by *C. rugosa*. There are several publication reporting the production of lipase by yeasts and their isolation source are shown in Table 1.

3. Screening methods of lipase producer

Different strategies for lipase enzyme screening have been proposed and used for identifying microorganisms producing lipases which involve culturing of microbial strains on solid agar medium or in liquid media containing different substrates. Screening of lipase producing ability can be broadly classified in two different type, there are direct and indirect screening methods.

3.1. Direct method (qualitative-on agar medium)

Solid agar media with added substrates or indicator dyes can be used for screening of lipolytic microorganisms. It is a useful rapid method of screening to evaluate individual microorganisms for their lipase enzyme

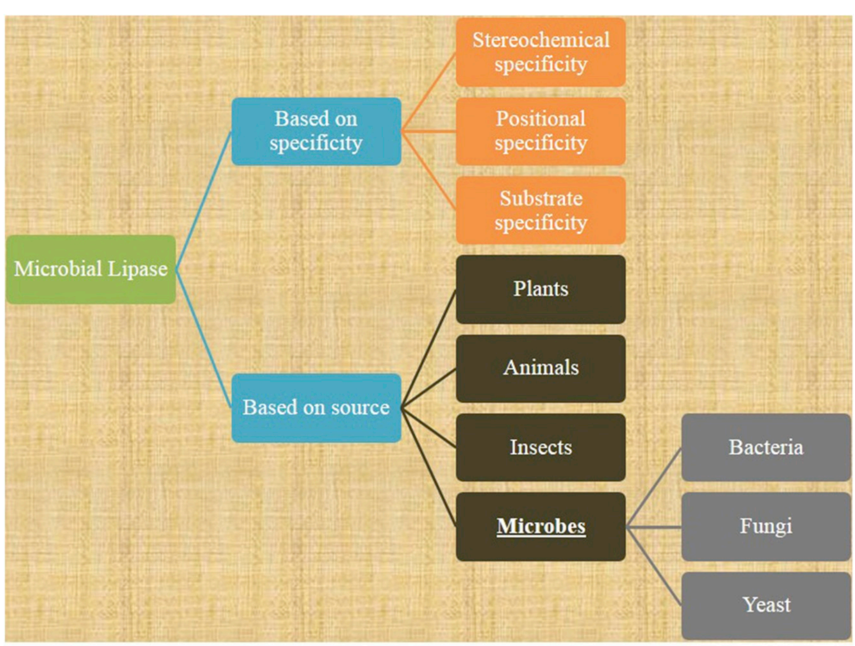

Fig. 1. Classification of microbial lipases based on sources.

Table 1
Microbial strains cited in the recent literature as potential lipase producer.

Microorganisms	Main source	Place of isolation/ obtained	References
Aeromonas caviae	Bacteria	Milk processing industry	Velu et al. (2012)
Acinetobacter sp.	Bacteria	Oil rich soil	Ahmed et al. (2010)
Bacillus sphaericus	Bacteria	MTCC 7542	Tamilarasan and Kumar (2012)
Bacillus sp.	Bacteria	Oil contaminated soil	Sharma et al. (2014)
Bacillus subtilis	Bacteria	PTCC 1720	Esmaeili et al. (2015)
Enterococcus durans	Bacteria	Fish processing waste	Ramakrishnan et al. (2012)
Staphylococcus warneri	Bacteria	Oil-contaminated soil	Yele and Desai (2015).
Thalassospira permensis	Bacteria	Sea water	Kai and Peisheng (2016)
Xanthomonas oryzae	Bacteria	Soil sample	Mo et al. (2016)
Yersinia enterocolitica	Bacteria	Refrigerators of a meat factory	Ji et al. (2015)
Aspergillus niger	Fungi	NCIM	Hosseinpour et al. (2012)
Meterhizium anisopliae	Fungi	Dairy effluent	Colla et al. (2016)
Penicillium chrysoenum	Fungi	Agro-industrial residues	Rajeswari et al. (2011)
Penicillum sp.	Fungi	Soybean meal and cheese	Rigo et al. (2010)
Rhizopus sp.	Fungi	Oil contaminated soil	Thota et al. (2012)
Rhizopus oryzae	Fungi	Waste cooking oily soil	Zhou et al. (2012)
Candida sp.	Yeast	ATCC 10231	Lan et al. (2011)
Cryptococcus sp.	Yeast	MTCC 5455	Thirunavukarasu et al. (2016)
Rhodotorula mucilaginosa	Yeast	MTCC	Pohanka (2019)
Saccharomyces cerevisiae	Yeast	Olive oil site	Ciafardini et al. (2013)
Trichosporon asahii	Yeast	Petroleum sludge soil	Kumar and Gupta (2008)
Yarrowia lipolytica	Yeast	ATCC 20460	Lopes et al. (2008)
Yamadazyma terventina	Yeast	Olive oils site	Ciafardini et al. (2013)

Note: MTCC- Microbial type culture collection, PTCC= Persian type culture collection, NCIM- National Collection of Industrial Microorganisms, ATCC – American type culture collection.

production (Mateos-Díaz et al., 2012). Based on the use of substrates and indicator dye, direct plate assay further sub classified into two different types.

3.1.1. Gel diffusion assays using various lipid substrates

These methods are used for screening lipolytic microbial strains based on the ability of break down the lipids incorporated in to solid media to form a clear zone of lipolysis (Lee et al., 2015). Based on the substrates utilised, various agar plate assays has been established inducing substrates such as Olive oil, Tributyrin, Tween 20 and Tween 80 are greatly preferred by many researchers (Bharathi et al., 2018; Kumar et al., 2012a,b; Lanka and abd Trinkle, 2017). Among those substrates assays, Tributyrin agar plate assay has been widely used for detection of lipase production due to their easy preparation and time consuming (Bharathi et al., 2018). Smitha et al. (2014) screened various marine fungi cultures (181) for their ability to secrete hydrolytic enzymes using nutrient agar supplemented with Tributyrin as substrate and found that large number of isolated fungus to be having lipolytic activity.

3.1.2. Gel diffusion assays using various indicator dyes

These methods involve use of various indicator dyes with various substrates to screen the lipase producing microbial strains. The dyes like phenol red, Rhodamine B, victoria blue, night blue can be used as indicator dye to screen. Rhodamine B added olive oil agar plate is a very common, sensitive and effective assay to identify active lipases. The basic principle and mechanism in this method involves interaction of hydrolyzed substrates with Rhodamine B (fluorescent dye) resulting in the formation of orange fluorescent halos around microbial colonies which can be visible upon UV irradiation (Dhiman and Chapadgaonkar, 2013; Kumar et al., 2012a,b; Niyonzima and More, 2013). Abrunhosa et al. (2013) reported that the combined Rhodamine B with olive oil to determine lipase production by *Aspergillus ibericus*. Screening of lipolytic microbes using indicator dye such as phenol red is also in wide practice.

3.2. Indirect method (quantitative-liquid medium)

Lipase producing ability of a microorganism can be determined using various quantitative methods such as titrimetric method, spectrophotometric method, chromatographic methods and molecular screening methods.

Titrimetric methods were routinely subjected to the estimation of lipase activity for more than half a century. Dayanandan et al. (2013) and Rigo et al. (2012) used alkali titration method to screen potential lipases producing *Penicillium crustosum* and *Aspergillus carneus* respectively. Recently, spectroscopic method using olive oil and p-NPP (p-nitrophenyl palmitate) as a substrate for quantitative screening potential lipase procedure has gained much attention due to their simple procedures (Velu et al., 2012; Romero et al., 2012). Rajan et al. (2011) quantified the liberated free fatty acids produced by the action of alkaline lipase from *Aspergillus fumigates* MTCC 9657 using HPTLC. Screening of various microbial strains using different qualitative and quantitative assay was shown in Table 2.

4. Production of microbial lipase

The microbial lipase are mostly extracellular and secreted into the lipase production medium. Submerged fermentation and solid state

Table 2
Screening methods of various lipase producing microorganisms.

Microorganisms	Screening method	Substrate	Reference
Streptomyces violascens	Spectrophotometer	p-NPP	Boran et al. (2019)
Aspergillus tamari	Titrimetric method	Olive oil	Das et al. (2016)
Burkholderia pyrrocinia	Spectrophotometer	p-NPP	Li et al. (2014)
Pseudomonas sp.	Spectrophotometer	p-NPP	Priji et al. (2017)
Rhizopus sp.	Spectrophotometer	p-NPP	Riyadi et al. (2017)
Bacillus sp.	Titrimetric method	Olive oil	Saraswat et al. (2018)
Bacillus sphaericus	Spectrophotometer	p-NPP	Tamilarasan and Kumar (2012)
Streptomyces sp.	Titrimetric method	Olive oil	Kumar et al. (2016)
Aeromonas caviae	Spectrophotometer	p-NPP	Velu et al. (2012)
Candida guillermondi	Spectrophotometer	p-NPP	Oliveira et al. (2016)
Penicillum chrysogenum	Gel diffusion - Indicator Dye	Rhodamine B	Rajeswari et al. (2011)
Aspergillus sydawii	Gel diffusion- lipid substrate	Tributyrin	Bindiya and Ramana (2014)
Trichoderma reesei	Gel diffusion- lipid substrate	Tributyrin	Rajesh et al. (2010)
Aspergillus sp.	Gel diffusion- lipid substrates	Palm oil and Tween-80	Nwuche and Ogbonna (2011)
Aspergillus fumigates	Chromatography (HPTLC)	–	Rajan et al. (2011)
Pseudozyma Antarctica	Molecular identification	–	Liu et al. (2010)

Note: p-NPP (para-Nitrophenylphosphate).

fermentation systems are widely used techniques to produce lipase enzyme from microorganisms.

4.1. Submerged fermentation system

Submerged fermentation system also called as liquid fermentation system. Submerged fermentation is a technique of cultivation of microorganisms in liquid broth medium which breaks down the supplied nutrients to compound (Costa et al., 2017). Further, the recovery and purification of lipases produced by SmF is relatively simple. SmF system mostly used for the production of lipase from bacterial strains. In commonly, oil carbon source such as vegetable oil, olive oil, coconut oil is common influencing factors in SmF system due to their sticky nature, even though various oils as a carbon source have been utilised to produce lipase enzyme from microbial strains especially olive oil, palm oil, sunflower oil, and almond oil has enhanced higher yield produced (Coradi et al., 2013; Colla et al., 2016; Salihu et al., 2012; Thakur, 2012).

4.2. Solid state fermentation system

Solid state fermentation system also called as solid substrate fermentation system and it is used several industries like food and pharmaceutical industries to produce compounds from microorganisms on solid substrate media (Mussatto et al., 2012; Barrios-González, 2012). Mostly, SSF used to produce fungal, mycelial and yeast lipases by using various solid substrate. For example, Sethi et al. (2016) used mustard oil as the substrate for lipase production by *Aspergillus sp.* in both SSF and liquid fermentation and the best result was observed in SSF. The advantages of producing lipase enzyme by SSF have been highlighted alongside the reduced production costs. Solid state fermentation (SSF) is an economical alternative for large scale production of enzymes that are produced by fungi. Therefore, production of lipases by solid state fermentation is a good and preferred option than submerged fermentation (Colla et al., 2015).

4.3. Factors influencing microbial lipase production

There are several factors strongly influence the production of lipase enzyme. The presence of an inducer particularly carbon sources as well as nitrogen sources and temperature, are the most considered factors.

4.3.1. Carbon source

In common, microbial lipase are produced upon induction of lipase producing genes. Carbon sources, particularly olive oil has a great role in induction of lipase enzyme in all type of microbial lipases. However, use of oil carbon sources (olive oil, palm oil, and other vegetable oils) for the induction of lipases has influence the recovery. A good yield of lipase production was observed by *Aspergillus terreus* when mustard seed oil used as a carbon source (Sethi et al., 2013). Combination of olive oil cake-sugar cane bagasse increases the lipase enzyme production in fungal strains. Enhancement of lipase production has been reported in bacterial strains when using olive oil compared to other (Zarevúcka, 2012). In contrast, Utilisation of Tween 80 has also aided in obtaining a better recovery of lipase produced by *Acinetobacter* sp. (Li et al., 2001). Along with vegetable oils are also widely used for better yield of higher lipases due to their cheap and readily available (Messias et al., 2009).

4.3.2. Nitrogen source

Nitrogen source is essential for microbial growth and enhancement of microbial lipase production. There are various organic and inorganic nitrogen sources such as ammonium salts, yeast extract, sodium nitrate, urea, peptone, tryptone, peptone has been used for the production of higher lipases from all form of microorganisms (Oliveira et al., 2016; Bose and Keharia, 2013; Priyanka et al., 2019; Das et al., 2016). Addition of urea to the culture medium for lipase production made the culturing of *Rhizopus* sp. to have higher lipolytic activity (Rodriguez et al., 2006). Similarly, peptone combination with other nitrogen extract has been used for lipase production by *Aspergillus* sp. (Colonia et al., 2019).

4.3.3. Effect of temperature on lipase production

Temperature also play an important role in the production of microbial lipases. Optimum temperature plays a vital role for the secretion of enzyme in shake flask method. Higher biomass concentration of lipase was observed at temperature 37 °C (Bharathi et al., 2018). Researchers reported that the slight increase in temperature up to 38 °C enhances the lipase production (de Souza et al., 2019; Yuan et al., 2016). Lower temperature decrease the lipase enzyme production and also higher temperature influence the enzyme activity.

4.3.4. Effect of pH on lipase production

Generally, bacterial lipases have alkaline pH optima or neutral pH. Researchers reported that the alkaline and neutral pH conditions enhances the lipase productions in bacterial and yeast cells (Ramakrishnan et al., 2016; Bharathi et al., 2018). A good yield of lipase production was observed by *Rhodotorula glutinis* HL25 when pH of the production medium was maintained at nearly neutral pH (Taskin et al., 2016). In contrast, acidic pH enhances the production of fungal lipases. Turati et al. (2019) observed enhanced lipase production and activity while maintain pH of the reaction medium at 4.

5. Purification of lipase enzyme

Purification of microbial lipases involves various steps depending on the intracellular or extracellular nature of the enzyme. In either case, produced proteins are further salted out by precipitation techniques using ammonium sulphate (Yang et al., 2016). Further the precipitated protein is subjected to dialysis and chromatography techniques. The choice of chromatography techniques differ based on the source of microorganisms and size of the proteins, mostly column chromatography technique used to purify lipases. Finally the crude fractions thus obtained are analysed for the presence of enzyme by several assay protocols, and applied further separation techniques like ion exchange, DEAE-sepharose and gel filtration chromatography (Unni et al., 2016; Zhou et al., 2012). A recent separation techniques used to purify microbial lipase has been shown in Table 3. A lipase from *Aspergillus niger* F044 was purified by precipitation with ammonium sulphate, DEAE-Sepharose FF (ion exchange), and Sephadex G-75 (gel filtration). A yield of 33% was obtained, while the purification factor was 73 (Zheng-Yu et al., 2007).

The microbial lipases size vary from every microorganisms to others. In case of bacterial lipase produced from *Pseudomonas aeruginosa* expressed an average molecular weight of 29 kDa (Unni et al., 2016). Whereas the fungal lipase was found to be have average weight of 27 kDa (Zhou et al., 2012), Lipase also exists as a monomer with average weight of 46 kDa in yeast as reported by Kumar et al. (2014).

6. Conclusion

Analysis of current literature shows microbial lipases are one of the most produced enzymes. Globally, many researches are conducting their studies on isolation, screening and optimizing the critical growth parameters for microbial strains to gain maximum yield of lipases. Qualitative screening has been achieved by using agar plate assay method with various substrates such as olive oil, Tributyrin and Tween 20/80. Further, quantitative screening has been achieved by culturing microorganisms in a liquid medium and subsequently identifying the lipase activity using various colorimetric and spectrophotometric methods. This type of screening methods, especially colorimetric methods helped to identify microbial strains which continuously produce lipases with higher yield. Production of microbial lipases can be carried out using

Table 3
Purification strategies recently used for various studies of microbial lipases.

Microorganisms	Purification techniques	Molecular weight (kDa)	References
Burkholderia ubonensis	Ammonium sulphate precipitation, anion exchange and sephadex 75 gel filtration chromatography	33	Yang et al. (2016)
Pseudomonas aeruginosa	Ammonium sulphate precipitation and sephadex G-100 gel filtration	29	Unni et al. (2016)
Idiomarina sp.	Ammonium sulphate precipitation, DEAE-sepharose and sephacryl S-200	67	Li et al. (2014)
Bacillus sp.	Ammonium sulphate precipitation and ion-exchange chromatography	24	Sivaramakrishnan and Incharoensakdi (2016)
Chromohalobacter sp.	Ammonium sulphate precipitation, sephacryl S-100	44	Xin and Hui-Ying (2012)
Penicillium sp.	Dialysis, Octyl Sepharose FF column	65.4	Daniela Flávia and M. Turati et al. (2019)
Aspergillus oryzae	Ammonium sulphate precipitation, DEAE-sepharose and sephadex G-100 gel filtration	27	Zhou et al. (2012)

Note: kDa denotes kilo Dalton.

both solid state and submerged fermentation system using various carbon and nitrogen source. Most of the literature reports supported that the solid state fermentation systems are better methods for microbial lipase production. The nutritional factors influencing microbial lipase production have been explored and have shown to be integral in enhancing lipase yield. Finally purification of lipases using different precipitation and chromatography techniques has been discussed and summarized. The microbial lipases have many applications and benefits in the food and agro-industries. The key advantage of choosing lipase as a biocatalyst in a number of organic transformations and also used for biodiesel production process.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bcab.2019.101368.

References

Abrunhosa, L., Oliveira, F., Dantas, D., Gonçalves, C., Belo, I., 2013. Lipase production by *Aspergillus ibericus* using olive mill wastewater. Bioproc. Biosyst. Eng. 36 (3), 285–291.

Ahmed, E.H., Raghavendra, T., Madamwar, D., 2010. An alkaline lipase from organic solvent tolerant *Acinetobacter* sp. EH28: application for ethyl caprylate synthesis. Bioresour. Technol. 101, 3628–3634.

Akil, E., Carvalho, T., Bárea, B., Finotelli, P., Lecomte, J., Torres, A.G., Villeneuve, P., 2016. Accessing regio-and typo-selectivity of *Yarrowia lipolytica* lipase in its free form and immobilized onto magnetic nanoparticles. Biochem. Eng. J. 109, 101–111.

Andualema, B., Gessesse, A., 2012. Microbial lipases and their industrial applications. Biotechnol. Adv. 11 (3), 100–118.

Aulakh, S.S., Prakash, R., 2010. Optimization of medium and process parameters for the production of lipase from an oil-tolerant *Aspergillus* sp. (RBD-01). J. Basic Microbiol. 50 (1), 37–42.

Avhad, M.R., Marchetti, J.M., 2019. Uses of enzymes for biodiesel production. In: *Advanced* Bioprocessing for Alternative Fuels, Biobased Chemicals, and Bioproducts. Woodhead Publishing, pp. 135–152.

Barrios-González, J., 2012. Solid-state fermentation: physiology of solid medium, its molecular basis and applications. Process Biochem. 47 (2), 175–185.

Bharathi, D., Rajalakshmi, G., Komathi, S., 2018. Optimization and production of lipase enzyme from bacterial strains isolated from petrol spilled soil. J. King Saud Univ. Sci. 1–4. https://doi.org/10.1016/j.jksus.2017.12.018.

Bindiya, P.A., Ramana, T., 2014. Optimization of lipase production from an indigenously isolated marine *Aspergillus sydowii* of Bay of Bengal. J. Biochem. Biotechnol. 3, 198–202.

Boran, R., Ugur, A., Sarac, N., Ceylan, O., 2019. Characterisation of Streptomyces violascens OC125-8 lipase for oily wastewater treatment. 3 Biotech 9 (1), 5. https://doi.org/10.1007/s13205-018-1539-x.

Bose, A., Keharia, H., 2013. Production, characterization and applications of organic solvent tolerant lipase by *Pseudomonas aeruginosa* AAU2. Biocatal. Agric. Biotechnol. 2 (3), 255–266.

Ciafardini, G., Zullo, B.A., Antonielli, L., Corte, L., Roscini, L., Cardinali, G., 2013. *Yamadazyma terventina* sp. nov., a yeast species of the Yamadazyma clade from Italian olive oils. Int. J. Syst. Evol. Microbiol. 63 (1), 372–376.

Colen, G., Junqueira, R.G., Moraes- Santos, T., 2006. Isolation and Screening of alkaline lipase- producing fungi from Brazilian Savanna soil. World J. Microbiol. Biotechnol. 22 (8), 881–885.

Colla, L.M., Ficanha, A.M., Rizzardi, J., Bertolin, T.E., Reinehr, C.O., Costa, J.A.V., 2015. Production and characterization of lipases by two new isolates of *Aspergillus* through solid-state and submerged fermentation. BioMed Res. Int. 2015, 1–9. https://doi.org/10.1155/2015/725959725959, 725959.

Colla, L.M., Primaz, A.L., Benedetti, S., Loss, R.A., Lima, M.D., Reinehr, C.O., Costa, J.A.V., 2016. Surface response methodology for the optimization of lipase production under submerged fermentation by filamentous fungi. Braz. J. Microbiol. 47 (2), 461–467.

Colonia, B.S.O., Woiciechowski, A.L., Malanski, R., Letti, L.A.J., Soccol, C.R., 2019. Pulp improvement of oil palm empty fruit bunches associated to solid-state biopulping and biobleaching with xylanase and lignin peroxidase cocktail produced by Aspergillus sp. LPB-5. Bioresour. Technol. 285, 121361.

Coradi, G.V., Da Visitação, V.L., De Lima, E.A., Saito, L.Y.T., Palmieri, D.A., Takita, M.A., De Lima, V.M.G., 2013. Comparing submerged and solid-state fermentation of agro-industrial residues for the production and characterization of lipase by *Trichoderma harzianum*. Ann. Microbiol. 63 (2), 533–540.

Costa, T.M., Hermann, K.L., Garcia-Roman, M., Valle, R.D.C.S.C., Tavares, L.B.B., 2017. Lipase production by *Aspergillus niger* grown in different agro-industrial wastes by solid-state fermentation. Braz. J. Chem. Eng. 34 (2), 419–427.

Daoud, L., Kamoun, J., Ali, M.B., Jallouli, R., Bradai, R., Mechichi, T., Aloulou, A., 2013. Purification and biochemical characterization of a halotolerant *Staphylococcus* sp. extracellular lipase. Int. J. Biol. Macromol. 57, 232–237.

Das, A., Bhattacharya, S., Shivakumar, S., Shakya, S., Sogane, S.S., 2016. Coconut oil induced production of a surfactant-compatible lipase from *Aspergillus tamarii* under submerged fermentation. J. Basic Microbiol. 57, 114–120.

Dayanandan, A., Rani, S., Shanmugavel, M., Gnanamani, A., Rajakumar, G.S., 2013. Enhanced production of *Aspergillus tamarii* lipase for recovery of fat from tannery fleshings. Braz. J. Microbiol. 44 (4), 1089–1095.

De Abreu, L., Fernandez-Lafuente, R., Rodrigues, R.C., Volpato, G., Ayub, M.A.Z., 2014. Efficient purification-immobilization of an organic solvent-tolerant lipase from *Staphylococcus warneri* EX17 on porous styrene-divinylbenzene beads. J. Mol. Catal. B Enzym. 99, 51–55.

de Souza, C.E.C., Ribeiro, B.D., Coelho, M.A.Z., 2019. Characterization and application of *Yarrowia lipolytica* lipase obtained by solid-state fermentation in the synthesis of different esters used in the food industry. Appl. Biochem. Biotechnol. 1–27.

Dhiman, S., Chapadgaonkar, S.S., 2013. Optimization of lipase production medium for a bacterial isolate. Inter. J. Chem. Technol. Res. 5, 2837–2843.

Divya, K., Padma, P.N., 2015. Psychrophilic yeast isolates for cold-active lipase production. Int. J. Sci. Prog. Res. 10, 93–97.

Dror, A., Kanteev, M., Kagan, I., Gihaz, S., Shahar, A., Fishman, A., 2015. Structural insights into methanol-stable variants of lipase T6 from *Geobacillus stearothermophilus*. Appl. Biochem. Biotechnol. 99 (22), 9449–9461.

Esmaeili, M., Yolmeh, M., Shakerardakani, A., Golivari, H., 2015. A central composite design for the optimizing lipase and protease production from *Bacillus subtilis* PTCC 1720. Biocatal. Agric. Biotechnol. 4 (3), 349–354.

Fang, Z., Xu, L., Pan, D., Jiao, L., Liu, Z., Yan, Y., 2014. Enhanced production of Thermomyces lanuginosus lipase in *Pichia pastoris* via genetic and fermentation strategies. J. Ind. Microbiol. Biotechnol. 41 (10), 1541–1551.

Geoffry, K., Achur, R.N., 2017. A novel halophilic extracellular lipase with both hydrolytic and synthetic activities. Biocatal. Agric. Biotechnol. 12, 125–130.

Gowthami, P., Muthukumar, K., Velan, M., 2015. Utilization of coconut oil cake for the production of lipase using *Bacillus coagulans* VKl1. Biocontrol Sci. 20 (2), 125–133.

He, Y.Q., Tan, T.W., 2006. Use of response surface methodology to optimize culture medium for production of lipase with *Candida* sp. 99-125. J. Mol. Catal. B Enzym. 43 (4), 9–14.

Hosseinpour, M.N., Najafpour, G.D., Younesi, H., Khorrami, M., Vaseghi, Z., 2012. Lipase production in solid state fermentation using *Aspergillus niger*: response surface methodology. Int. J. Eng. 25, 151–159.

Javed, S., Azeem, F., Hussain, S., Rasul, I., Siddique, M.H., Riaz, M., Nadeem, H., 2018. Bacterial lipases: a review on purification and characterization. Prog. Biophys. Mol. Biol. 132, 23–34.

Ji, X., Chen, G., Zhang, Q., Lin, L., Wei, Y., 2015. Purification and characterization of an extracellular cold-adapted alkaline lipase produced by psychrotrophic bacterium *Yersinia enterocolitica* strain KM1. J. Basic Microbiol. 55 (6), 718–728.

Joseph, B., Upadhyaya, S., Ramteke, P., 2011. Production of cold-active bacterial lipases through semisolid state fermentation using oil cakes. Enzym. Res. 1–6, 2011.

Kai, W., Peisheng, Y., 2016. Optimization of lipase production from a novel strain *Thalassospira permensis* M35-15 using response surface methodology. Bioengineered 7 (5), 298–303.
Kaur, G., Singh, A., Sharma, R., Sharma, V., Verma, S., Sharma, P.K., 2016. Cloning, expression, purification and characterization of lipase from *Bacillus licheniformis*, isolated from hot spring of Himachal Pradesh, India. 3 Biotech 6 (1), 49.
Khan, F.I., Lan, D., Durrani, R., Huan, W., Zhao, Z., Wang, Y., 2017. The lid domain in lipases: structural and functional determinant of enzymatic properties. Front. Bioeng. Biotechnol. 5, 16.
Kumar, A., Dhar, K., Kanwar, S.S., Arora, P.K., 2016. Lipase catalysis in organic solvents: advantages and applications. Biol. Proced. Online 18 (1), 2.
Kumar, A., Kanwar, S.S., 2012. Lipase production in solid-state fermentation (SSF): recent developments and biotechnological applications. Dyn. Biochem. Process Biotechnol. Mol. Biol. 6 (1), 13–27.
Kumar, D., Kumar, L., Nagar, S., Raina, C., Parshad, R., Gupta, V.K., 2012. Screening, isolation and production of lipase/esterase producing *Bacillus* sp. strain DVL2 and its potential evaluation in esterification and resolution reactions. Arch. Appl. Sci. Res. 4 (4), 1763–1770.
Kumar, D., Kumar, L., Nagar, S., Raina, C., Parshad, R., Gupta, V.K., 2012. Screening, isolation and production of lipase/esterase producing *Bacillus* sp. strain DVL2 and its potential evaluation in esterification and resolution reactions. Arch. Appl. Sci. Res. 4 (4), 1763–1770.
Kumar, K., Usha, K.Y., Satyanarayana, S.V., Sailaja, V., 2014. Characterization of partially purified lipase from *Saccharomyces cerevisiae*. Int. J. Pharm. Pharm. Sci. 6, 514–517.
Kumar, S.S., Gupta, R., 2008. An extracellular lipase from *Trichosporon asahii* MSR 54: medium optimization and enantioselective deacetylation of phenyl ethyl acetate. Process Biochem. 43 (10), 1054–1060.
Lan, D., Hou, S., Yang, N., Whiteley, C., Yang, B., Wang, Y., 2011. Optimal production and biochemical properties of a lipase from *Candida albicans*. Int. J. Mol. Sci. 12 (10), 7216–7237.
Lan, D., Qu, M., Yang, B., Wang, Y., 2016. Enhancing production of lipase MAS1 from marine *Streptomyces* sp. strain in *Pichia pastoris* by chaperones co-expression. Electron. J. Biotechnol. 22, 62–67.
Lanka, S., abd Trinkle, T.B., 2017. Screening and isolation of lipase producing fungi from marine water obtained from machilipatnam costal region. Int. J. Pharmacog. Phytochem. Res. 7, 928–932.
Lee, L.P., Karbul, H.M., Citartan, M., Gopinath, S.C., Lakshmipriya, T., Tang, T.H., 2015. Lipase-secreting *Bacillus* species in an oil-contaminated habitat: promising strains to alleviate oil pollution. BioMed Res. Int. 1–10, 2015.
Li, C.Y., Cheng, C.Y., Chen, T.L., 2001. Production of *Acinetobacter radioresistens* lipase using Tween 80 as the carbon source. Enzym. Microb. Technol. 29, 258–263.
Li, X., Qian, P., Wu, S.G., Yu, H.Y., 2014. Characterization of an organic solvent tolerant lipase from *Idiomarina* sp. W33 and its application for biodiesel production using Jatropha oil. Extremophiles 18, 171–178.
Liu, D., Trodler, P., Eiben, S., Koschorreck, K., Müller, M., Pleiss, J., Hauer, B., 2010. Rational design of *Pseudozyma antarctica* lipase B yielding a general esterification catalyst. Chembiochem 11 (6), 789–795.
Lopes, M., Gomes, N., Gonçalves, C., Coelho, M.A.Z., Mota, M., Belo, I., 2008. *Yarrowia lipolytica* lipase production enhanced by increased air pressure. Lett. Appl. Microbiol. 46 (2), 255–260.
Mabizela-Mokoena, N.B., Limani, S.W., Ncube, I., Piater, L.A., Litthauer, D., Nthangeni, M.B., 2017. Genetic determinant of *Bacillus pumilus* lipase lethality and its application as positive selection cloning vector in *Escherichia coli*. Protein Expr. Purif. 137, 43–51.
Maiangwa, J., Ali, M.S.M., Salleh, A.B., Rahman, R.N.Z.R., Shariff, F.M., Leow, T.C., 2015. Adaptational properties and applications of cold-active lipases from psychrophilic bacteria. Extremophiles 19 (2), 235–247.
Maldonado, R.R., Lopes, D.B., Aguiar-Oliveira, E., Kamimura, E.S., Macedo, G.A., 2016. A review on geotrichum lipases: production, purification, immobilization and applications. Chem. Biochem. Eng. 30 (4), 439–454.
Mateos-Díaz, E., Rodríguez, J.A., de los Ángeles Camacho-Ruiz, M., Mateos-Díaz, J.C., 2012. High-throughput screening method for lipases/esterases. In: Lipases and Phospholipases. Human Press, pp. 89–100.
Messias, J.M., da Costa, B.Z., de Lima, V.M., Dekker, R.F., Rezende, M.I., Krieger, N., Barbosa, A.M., 2009. Screening *Botryosphaeria* species for lipases: production of lipase by *Botryosphaeria ribis* EC-01 grown on soybean oil and other carbon sources. Enzym. Microb. Technol. 45, 426–431.
Mo, Q., Liu, A., Guo, H., Zhang, Y., Li, M., 2016. A novel thermostable and organic solvent-tolerant lipase from *Xanthomonas oryzae* pv. oryzae YB103: screening, purification and characterization. Extremophiles 20 (2), 157–165.
Moftah, O.A.S., Grbavčić, S., Žuža, M., Luković, N., Bezbradica, D., Knežević-Jugović, Z., 2012. Adding value to the oil cake as a waste from oil processing industry: production of lipase and protease by *Candida utilis* in solid state fermentation. Appl. Biochem. Biotechnol. 166 (2), 348–364.
Mouad, A.M., Taupin, D., Lehr, L., Yvergnaux, F., Porto, A.L.M., 2016. Aminolysis of linoleic and salicylic acid derivatives with Candida antarctica lipase B: A solvent-free process to obtain amphiphilic amides for cosmetic application. J. Mol. Catal. B Enzym. 126, 64–68.
Mussatto, S.I., Ballesteros, L.F., Martins, S., Teixeira, J.A., 2012. Use of agro-industrial wastes in solid-state fermentation processes. Ind. Waste 274.
Niyonzima, F.N., More, S.S., 2013. Screening and identification of a novel alkaline lipase producing bacterium. Int. J. Pharm. Biol. Sci. 4 (2), 1037–1045.
Nwuche, C.O., Ogbonna, J.C., 2011. Isolation of lipase producing fungi from palm oil mill effluent (POME) dump sites at Nsukka. Braz. Arcg. Biol. Techn 54 (1), 113–116.
Oliveira, F., Moreira, C., Salgado, J.M., Abrunhosa, L., Venâncio, A., Belo, I., 2016. Olive pomace valorization by *Aspergillus* species: lipase production using solid-state fermentation. J. Sci. Food Agric. 96 (10), 3583–3589.
Pandey, N., Dhakar, K., Jain, R., Pandey, A., 2016. Temperature dependent lipase production from cold and pH tolerant species of *Penicillium*. Mycosphere 7 (10), 1533–1545.
Priji, P., Sajith, S., Faisal, P.A., Benjamin, S., 2017. Pseudomonas sp. BUP6 produces a thermotolerant alkaline lipase with trans-esterification efficiency in producing biodiesel. 3 Biotech 7 (6), 369. https://doi.org/10.1007/s13205-017-0999-8.
Pohanka, M., 2019. Biosensors and bioassays based on lipases, principles and applications, a review. Molecules 24 (3), 616.
Priyanka, P., Kinsella, G., Henehan, G.T., Ryan, B.J., 2019. Isolation, purification and characterization of a novel solvent stable lipase from *Pseudomonas reinekei*. Protein Expr. Purif. 153, 121–130.
Rajan, A., Kumar, D.S., Nair, A.J., 2011. Isolation of a novel alkaline lipase producing fungus *Aspergillus fumigatus* MTCC 9657 from aged and crude rice bran oil and quantification by HPTLC. Int. J. Biol. Chem. 5 (11), 116–126.
Rajendran, A., Palanisamy, A., Thangavelu, V., 2008. Evaluation of medium components by Plackett-Burman statistical design for lipase production by *Candida rugosa* and kinetic modeling. Chin. J. Biotechnol. 24 (3), 436–444.
Rajesh, E.M., Arthe, R., Rajendran, R., Balakumar, C., Pradeepa, N., Anitha, S., 2010. Investigation of lipase production by *Trichoderma reesei* and optimization of production parameters. Electron. J. Environ. Agric. Food Chem. 9, 1177–1189.
Rajeswari, J., Palaniswamy, M., Raphy, Pinky, Padmapriya, B., 2011. Utilization of mixed agro industrial by - products for alkaline lipase production from *Penicillim chrysogenum*. Int. J. Pharm. Biol. Arch. 2, 682–691.
Ramakrishnan, V., Balakrishnan, B., Rai, A.K., Narayan, B., Halami, P.M., 2012. Concomitant production of lipase, protease and enterocin by *Enterococcus faecium* NCIM5363 and *Enterococcus durans* NCIM5427 isolated from fish processing waste. Int. Aquat. Res. 4 (1), 14.
Ramakrishnan, V., Goveas, L.C., Suralikerimath, N., Jampani, C., Halami, P.M., Narayan, B., 2016. Extraction and purification of lipase from *Enterococcus faecium* MTCC5695 by PEG/phosphate aqueous-two phase system (ATPS) and its biochemical characterization. Biocatal. Agric. Biotechnol. 6, 19–27.
Ramyasree, S., Dutta, J.R., 2013. The effect of process parameters in enhancement of lipase production by co-culture of lactic acid bacteria and their mutagenesis study. Biocatal. Agric. Biotechnol. 2 (4), 393–398.
Resina, D., Maurer, M., Cos, O., Arnau, C., Carnicer, M., Marx, H., Ferrer, P., 2009. Engineering of bottlenecks in *Rhizopus oryzae* lipase production in *Pichia pastoris* using the nitrogen source-regulated FLD1 promoter. N. Biotech. 25 (6), 396–403.
Rigo, E., Ninow, J.L., Tsai, S.M., Durrer, A., Foltran, L.L., Remonatto, D., Di Luccio, M., 2012. Preliminary characterization of novel extra-cellular lipase from *Penicillium crustosum* under solid-state fermentation and its potential application for triglycerides hydrolysis. Food Bioproc. Tech. 5 (5), 1592–1600.
Rigo, E., Ninow, J.L., Di Luccio, M., Oliveira, J.V., Polloni, A.E., Remonatto, D., Arbter, F., Vardanega, R., de Oliveira, D., Treichel, H., 2010. Lipase production by solid fermentation of soybean meal with different supplements. LWT-Food Sci. Technol. 43, 1132–1137.
Riyadi, F.A., Alam, M.Z., Salleh, M.N., Salleh, H.M., 2017. Optimization of thermostable organic solvent-tolerant lipase production by thermotolerant *Rhizopus* sp. using solid-state fermentation of palm kernel cake. 3 Biotech 7 (5), 300.
Rodriguez, J.A., Mateos, J.C., Nungaray, J., González, V., Bhagnagar, T., Roussos, S., Cordova, J., Baratti, J., 2006. Improving lipase production by nutrient source modification using *Rhizopus homothallicus* cultured in solid state fermentation. Process Biochem. 41, 2264–2269.
Romero, C.M., Pera, L.M., Loto, F., Vallejos, C., Castro, G., Baigori, M.D., 2012. Purification of an organic solvent-tolerant lipase from *Aspergillus niger* MYA 135 and its application in ester synthesis. Biocatal. Agric. Biotechnol. 1 (1), 25–31.
Roy, M., Kumar, R., Ramteke, A., Sit, N., 2018. Identification of lipase producing fungus isolated from dairy waste contaminated soil and optimization of culture conditions for lipase production by the isolated fungus. J. Microbiol. Biotechnol. Food Sci. 8 (1).
Sahu, G.K., Martin, M., 2011. Optimization of growth conditions for the production of extracellular lipase by bacterial strains from dairy industry effluents. Biotechnol. Bioinf. Bioeng. 1 (3), 305–311.
Salihu, A., Alam, M.Z., AbdulKarim, M.I., Salleh, H.M., 2012. Lipase production: an insight in the utilization of renewable agricultural residues. Resour, Conserv. Recycling 58, 36–44.
Sangeetha, R., Geetha, A., Arulpandi, I., 2010. Concomitant production of protease and lipase by *Bacillus licheniformis* VSG1: production, purification and characterization. Braz. J. Microbiol. 41 (1), 179–185.
Saraswat, R., Bhushan, I., Gupta, P., Kumar, V., Verma, V., 2018. Production and purification of an alkaline lipase from *Bacillus* sp. for enantio-selective resolution of (±)-Ketoprofen butyl ester. 3 Biotech 8 (12), 491.
Sarmah, N., Revathi, D., Sheelu, G., Rani, K.Y., Sridhar, S., Mehtab, V., Sumana, C., 2018. Recent advances on sources and industrial applications of lipases. Biotechnol. Prog. 34 (1), 5–28.
Sethi, B.K., Nanda, P.K., Sahoo, S., 2016. Characterization of biotechnologically relevant extracellular lipase produced by *Aspergillus terreus* NCFT 4269.10. Braz. J. Microbiol. 47, 143–149.
Sethi, B.K., Rout, J.R., Das, R., Nanda, P.K., Sahoo, S.L., 2013. Lipase production by Aspergillus terreus using mustard seed oil cake as a carbon source. Ann. Microbiol. 63 (1), 241–252.
Singh, A.K., Mukhopadhyay, M., 2012. Overview of fungal lipase: a review. Appl. Biochem. Biotech 166 (2), 486–520.

Sharma, D., Kumbhar, B.K., Verma, A.K., Tewari, L., 2014. Optimization of critical growth parameters for enhancing extracellular lipase production by alkalophilic *Bacillus* sp. Biocatal. Agric. Biotechnol. 3 (4), 205–211.
Sivaramakrishnan, R., Incharoensakdi, A., 2016. Purification and characterization of solvent tolerant lipase from *Bacillus* sp. for methyl ester production from algal oil. J. Biosci. Bioeng. 121 (5), 517–522.
Smitha, S.L., Correya, N.S., Philip, R., 2014. Marine fungi as a potential source of enzymes and antibiotics. Int. J. Res. Mar. Sci. 3 (1), 5–10.
Su, F., Peng, C., Li, G.L., Xu, L., Yan, Y.J., 2016. Biodiesel production from woody oil catalyzed by *Candida rugosa* lipase in ionic liquid. Renew. Energy 90, 329–335.
Suci, M., Arbianti, R., Hermansyah, H., 2018. Lipase production from *Bacillus subtilis* with submerged fermentation using waste cooking oil. IOP Conf. Ser. Earth Environ. Sci. 105 (1), 012126.
Tamilarasan, K., Kumar, M.D., 2012. Purification and characterization of solvent tolerant lipase from *Bacillus sphaericus* MTCC 7542. Biocatal. Agric. Biotechnol. 1 (4), 309–313.
Tan, J.S., Abbasiliasi, S., Ariff, A.B., Ng, H.S., Bakar, M.H.A., Chow, Y.H., 2018. Extractive purification of recombinant thermostable lipase from fermentation broth of *Escherichia coli* using an aqueous polyethylene glycol impregnated resin system. 3 Biotech 8 (6), 288.
Taskin, M., Ucar, M.H., Unver, Y., Kara, A.A., Ozdemir, M., Ortucu, S., 2016. Lipase production with free and immobilized cells of cold-adapted yeast *Rhodotorula glutinis* HL25. Biocatal. Agric. Biotechnol. 8, 97–103.
Thakur, S., 2012. Lipases, its sources, properties and applications: a review. Int. J. Sci. Eng. Res. 3 (7), 1–29.
Thapa, S., Li, H., OHair, J., Bhatti, S., Chen, F.C., Al Nasr, K., Zhou, S., 2019. Biochemical characteristics of microbial enzymes and their significance from industrial perspectives. Mol. Biotechnol. 1–23.
Thirunavukarasu, K., Purushothaman, S., Sridevi, J., Aarthy, M., Gowthaman, M.K., Nakajima-Kambe, T., Kamini, N.R., 2016. Degradation of poly (butylene succinate) and poly (butylene succinate-co-butylene adipate) by a lipase from yeast Cryptococcus sp. grown on agro-industrial residues. Int. Biodeterior. Biodegrad. 110, 99–107.
Thota, P., Bhogavalli, P.K., Rao, V.P., Sreerangam, V., 2012. Screening and identification of potential fungal strains for the production of extracellular lipase from soil. Plant Sci. Feed. 2, 79–84.
Treichel, H., de Oliveira, D., Mazutti, M.A., Di Luccio, M., Oliveira, J.V., 2010. A review on microbial lipases production. Food Bioprocess Technol. 3 (2), 182–196.
Tripathi, R., Singh, J., kumar Bharti, R., Thakur, I.S., 2014. Isolation, purification and characterization of lipase from *Microbacterium* sp. and its application in biodiesel production. Energy Procedia 54, 518–529.
Turati, D.F.M., Almeida, A.F., Terrone, C.C., Nascimento, J.M., Terrasan, C.R., Fernandez-Lorente, G., Carmona, E.C., 2019. Thermotolerant lipase from *Penicillium* sp. section *Gracilenta* CBMAI 1583: effect of carbon sources on enzyme production, biochemical properties of crude and purified enzyme and substrate specificity. Biocatal. Agric. Biotechnol. 17, 15–24.
Ülker, S., Karaoğlu, Ş.A., 2012. Purification and characterization of an extracellular lipase from Mucor hiemalis f. corticola isolated from soil. J. Biosci. Bioeng 114 (4), 385–390.
Unni, K.N., Priji, P., Sajith, S., Faisal, P.A., Benjamin, S., 2016. *Pseudomonas aeruginosa* strain BUP2, a novel bacterium inhabiting the rumen of Malabari goat, produces an efficient lipase. Biol. Bratisl. 71, 378–387.
Velu, N., Divakar, K., Nandhinidevi, G., Gautam, P., 2012. Lipase from *Aeromonas caviae* AU04: isolation, purification and protein aggregation. Biocatal. Agric. Biotechnol. 1 (1), 45–50.
Xin, Li, Hui-Ying, Yu, 2012. Characterization of a novel extracellular lipase from a halophilic isolate, *Chromohalobacter* sp. LY7-8. Afr. J. Microbiol. Res. 6, 3516–3522.
Yang, W., He, Y., Xu, L., Zhang, H., Yan, Y., 2016. A new extracellular thermo-solventstable lipase from *Burkholderia ubonensis* SL-4: identification, characterization and application for biodiesel production. J. Mol. Catal. B Enzym. 126, 76–89.
Yele, V.U., Desai, K., 2015. A new thermostable and organic solvent-tolerant lipase from *Staphylococcus warneri*; optimization of media and production conditions using statistical methods. Biotechnol. Appl. Biochem. 175 (2), 855–869.
Yuan, D., Lan, D., Xin, L.R., Wang, Y., 2016. Screening and characterization of thermostable lipase from marine *Streptomyces* Sp. Strain w007. Biotechnol. Appl. Biochem. 63 (1), 16–22.
Zarevúcka, M., 2012. Olive Oil as Inductor of Microbial Lipase. Olive Oil-Constituents, Quality, Health Properties and Bioconversions. InTech Europe, Rijeka, Croatia, pp. 457–470.
Zheng, C., 2018. Screening and identification of lipase producing bacterium. In: *IOP* Conference Series: Earth and Environmental Science, vol. 108. IOP Publishing, 042088, 4.
Zheng-Yu, S.H.U., Jiang-Ke, Y.A.N.G., Yun-Jun, Y.A.N., 2007. Purification and characterization of a lipase from *Aspergillus niger* F044. Chin. J. Biotechnol. 23 (1), 96–101.
Zhou, J., Chen, W.W., Jia, Z.B., Huang, G.R., Hong, Y., Tao, J.J., Luo, X.B., 2012. Purification and characterization of lipase produced by *Aspergillus oryzae* CJLU-31 isolated from waste cooking oily soil. Am. J. Food Technol. 7 (10), 596–608.