RESEARCH PAPER

Waste Cooking Oil-Based Biodiesel: A Pathway toward Sustainable and Circular Energy System

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ABSTRACT

The primary aim of this review paper is to present a step-by-step detail, problem and solutions to boost the output of the biodiesel production by incorporating different microorganisms that have the ability of producing the enzyme to transform used cooking oil to biodiesel. The article discusses the current developments in biodiesel production, with an emphasis on the use of waste cooking oils (WCOs) as a green raw material. The existing methods of transesterification, including heterogeneous acid catalysts, alkali catalysts and enzyme-catalyzed reactions are also outlined. The enzymes required in such kinds of reactions are also addressed as well as the benefits of the enzymatic method compared to the other methods. The most promising enzymes to convert biodiesel are the lipases at the moment. The tenets of the circular economy are observed by employing waste cooking oils (WCOs) in the biodiesel production process, as well as by tackling the issues of poor disposal of these products. Finally, the possibility of biodiesel production through the utilization of leftover cooking oils provides an opportunity to decrease fossil fuel reliance, which can help advance a sustainable agenda and the use of the circular economy.

Keywords: biodiesel, waste cooking oil, transesterification, enzyme catalyst, circular economy, sustainability.
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1. INTRODUCTION

The need to discover alternative renewable fuels has led to more research because of the escalating energy demand and the estimated scarcity of fossil fuel reserves. By 2050, there will be a 50% rise in the world's energy use[1]. It is imperative that we move toward low-carbon, renewable energy sources that can take the place of conventional ones. The production and consumption of energy have radically altered due to the global quest to find sustainable sources of energy in the wake of climate change and the exhaustion of fossil fuels.

The need to switch to ecologically friendly and renewable energy sources is becoming more pressing as worries about the effects on the environment increase. Biodiesel is one promising option in the field of renewable energy. Biodiesel is officially declared as a renewable fuel created in the transesterification of triglycerides of edible oils, non-edible oils and waste oils,[2]. Biodiesel is a long chain molecule with a carbon skeleton having over 12 carbon atoms and a compound that consists of monoalkyl esters produced by the long fatty acids (LCFAs). B100 is the name of this 100% pure biodiesel product.

A variety of resources, both edible and inedible, from plant and animal sources have been used in biodiesel's Production. The first generation of biofuels,[3], came from food sources, namely oils from crops including coconut, canola, maize, jatropha, palm oil, mustard, rapeseed, soybean, peanuts, sunflower, etc. 2ndgeneration come from non-edible oil or used cooking oil While 3rdgeneration biofuels use novel biomass production techniques, such as using algae as a key feedstock [4,5,6]. Therefore, 3rdgeneration biofuels, such as algae-based biofuels, offer novel production of feedstock's techniques to boost yields and cut prices, whereas 2ndgeneration biofuels seek to avoid utilizing food as a fuel source. However, there are drawbacks to 1st to 3rdgeneration biodiesel feedstocks, such as limited acreage, low yield, adaptability to environment, high prices, and a food supply vulnerability that can raise the price of food products [7,8]. 4thgeneration biofuels are the subject of ongoing research with the goal of providing green energy that is sustainable.

Concerns regarding the possible competition for vital resources, such as energy, water, and land for the production of food and fuel resources have been raised by research. This emphasizes the necessity of locating low-cost, non-food feedstocks for the manufacturing of biodiesel. Because of this, scientists have looked at producing biodiesel from non-food, alternative sources[10,11]. Waste cooking oils are becoming more widely acknowledged as a viable feedstock choice with both environmental responsibility and transformational promise. They provide a way to bridge the gap between sustainable energy generation and waste management while avoiding conflict with food resources. However, leftover cooking oil has a high concentration of free fatty acids that would be transformed into sap during the traditional trans-esterification process—a process known as saponification. Saponification significantly reduces the output and purity of biodiesel production, but it raises production costs since more feedstock pretreatment, catalyst, polishing, and purifying procedures are required. Used cooking oil is still a better option in comparison to other feedstocks to supply oil for biodiesel if biodiesel is converted under the techniques that prevent saponification, notwithstanding the drawbacks of utilizing used cooking oil as a feedstock.

In different studies, researchers have used a variety of terminology to describe edible cooking oil. The phrase "waste cooking oil" (WCO)[12,13]. As an alternative, it has been referred to as "used cooking oil" (UCO)[14] and "used frying oil" (UFO)[15].

2. WASTE COOKING OIL AS A SUSTAINABLE FEEDSTOCK

Several researchers have investigated the feasibility of employing WCO as a prospective source for biodiesel synthesis, including [15,16,17,18,19]. However, the sustainability of using WCO, or waste cooking oil to produce biodiesel has not been sufficiently taken into account in these studies. In the context of the circular economy, WCO shows promise as a useful resource. Significant amounts of WCO are present all over the planet[20]. However, gathering this trash is a significant problem because large volumes of spent cooking oil are illegally dumped in waterways and landfills, which pollutes the environment [20,21]. The amount of vegetable oil produced worldwide was 208.8 million metric tons in 2021–2022, and it is anticipated to reach 217 million metric tons in 2022–2023[22]. Growing demands brought on by the world's population expansion are blamed for this production boom, which has resulted in a corresponding rise in waste cooking oil. The amount of WCO produced differs greatly amongst nations due to their diverse culinary traditions[23].

Over 15 million metric tons of Waste Cooking Oils (WCOs) are expected to be produced annually worldwide from both residential and commercial sources. The European Union (EU) contributes approximately 1 million tons annually, which is significant in this context[24]. Additionally, Table 1 shows the yearly manufacturing of waste cooking oil (WCO) in particular chosen nations [20,21].

Table 1: shows the yearly manufacturing of waste cooking oil in a few chosen nation [21].

Nation	Amount (million tons annually)
Europe	0.7-10
China	4.5
Canada	0.12
Japan	0.45-0.57
Ireland	0.153
UK	0.2
Taiwan	0.07
Malaysia	0.5
USA	10

3. CONVERSION TECHNOLOGIES FOR WCO-BASED BIODIESEL

The primary processing methods for turning vegetable oils into fuel include mixing, pyrolysis, micro-emulsification, and transesterification[25,26]. Transesterification is by far the most crucial stage in converting vegetable and animal fats into a cleaner, safer fuel for the environment.

3.1 Transesterification

The most widely used process for making biodiesel is transesterification of oils from vegetable, which produces the best results [27]. The process of swapping an ester compound's alk-oxy group with another alcohol is known as transesterification. As intermediary molecules, monoglycerides and diglycerides are produced in a series of three sequential, reversible reactions. The stoichiometric reaction calls for one mol of triglycerides and three mol of alcohol (Figure 1).

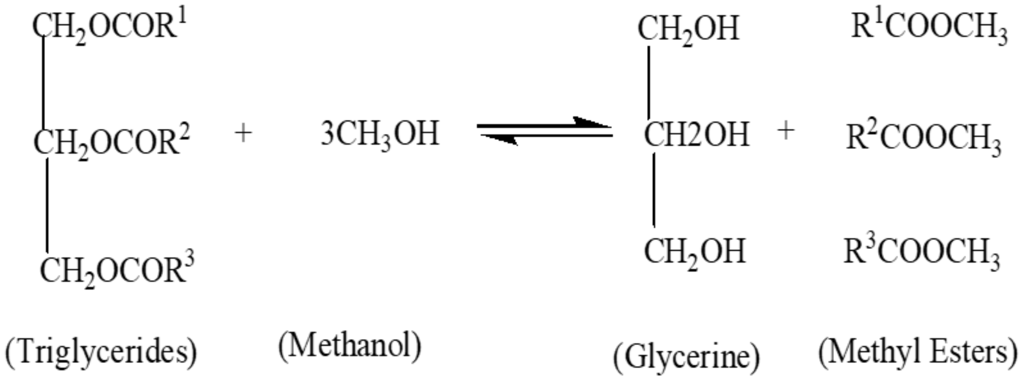

Figure 1. Triglyceride transesterification reaction.

Because the reaction is reversible, more alcohol is employed to move the equilibrium to the side of the products [28, 29].

3.2 Catalyst Used

The transesterification process requires an alkali or acid catalyst, or a heterogeneous catalyst such as an enzyme [30,31,32,33,34,35]. Bases catalyze the reaction by removing a proton from the alcohol, whereas acids catalyze the reaction by adding a proton to the carbonyl group, which also increases its reactivity.

Alkali catalyst

Alkaline media are commonly used in the commercial production process to trans esterify the oil or fats in the presence of alcohol, creating glycerol and methyl esters of fatty acids. The exact chemical mechanism of alkali-catalyzed transesterification has been determined to consist of three stages [25,36]. Potassium hydroxide or sodium hydroxide, along with either methanol or ethanol and vegetable oil, make up the basic catalyst. Sodium hydroxide is commonly used in large-scale processing due to its lower cost and high product yield[37]. Compared to acid-catalyzed transesterification, alkali-catalyzed transesterification is substantially quicker and less damaging to industrial machinery. As a result, it is the most widely utilized commercial procedure [25,38,39] Although alkaline catalysis provides rapid reaction times and high conversion rates of triglycerides to their corresponding methyl esters, it has some disadvantages. The procedure requires a lot of energy, recovering glycerol is challenging, eliminating the product's alkaline catalyst is necessary, the alkaline wastewater produced needs to be treated, and the presence of water and free fatty acids significantly impedes the reaction [25,40].

Catalytic acid

Conventional methods of producing biodiesel also involve catalysing the transesterification process with an acid. H_2SO_4, sulphonic acids and HCl in methanol are the usual acid catalysts but the most commonly used is H_2SO_4[41,42.] The carbonyl group of the ester is protonated during the acid-catalyzed transesterification of vegetable oil. This results in carbonation, which creates a tetrahedral intermediate following an alcohol nucleophilic attack. In order to create a fresh ester and regenerate the catalyst 29, these intermediate removes glycerol[29]. If the triglyceride contains more water and free fatty acids, acid catalysts are employed [43].

Heterogeneous catalysts

The transesterification of vegetable oils has also been catalysed by heterogeneous catalysts, including amorphous zirconia, enzymes, potassium zirconias and titanium, heterogenized on organic polymers. The additional expenses related to the homogeneous NaOH necessary to remove the catalyst following trans-esterification are eliminated by the heterogeneous catalyst.

Enzyme as a catalyst

It has recently been shown that enzymatic catalysis specifically synthesizes alkyl esters, producing a high-quality item, enabling simple recovery of glycerol, full transesterification of the free fatty acids, and the procedure with yields of at least 90% under mild circumstances. Thus, an environmentally friendly biotechnological substitute for chemical catalysis is the enzymatic process [44, 45, 46].

Table 2. A comparison of the various transesterification techniques used to produce biodiesel [47,48,49].

Variables	Alkali Catalyst	Acid Catalyst	Lipase Catalyst
Reaction Temp (°C)	60 to70	55 to 80	30 to 40
Raw materials' free fatty acids	Saponified	Esters of Methyl	Esters of Methyl
Water in the raw substance	Interference with the Reaction	Interference with the Reaction	No influences
Methyl esters' yields	Average	Average	Higher
Glycerol recovery	Complicated	Complicated	Simple
Methyl ester purification	Washing repeatedly	Washing repeatedly	None
Production price of catalyst	Cheap	Cheap	Relatively Cheap
Timing of Reaction	Short	Short (9 h)	Long (36 h)

Fatty acid alkyl ester and glycerol are the byproducts of the enzyme lipase, which is employed in the synthesis of biodiesel. It is possible to extract lipases from a variety of sources, including, fungus bacteria, and yeast.

Both extracellular and intracellular lipases can perform the enzymatic catalyzed transesterification. Due to the immediate esterification of free fatty acids into biodiesel, lipase-catalyzed transesterification is more suitable for biodiesel production from feedstocks that contain high levels of water and free fatty acids, such as greases, waste or recycled oils [50,51,52,53]. The desirable characteristics of this alternative way of producing biodiesel are biotechnological, environmental acceptability of the biocompatibility and biodegradability processes when using lipase as a catalyst [38,44].

When using lipases to catalyze the transesterification process for the production of biodiesel, there are two primary problems: the enzyme is less active than chemical catalysts and can be inactivated by lower alcohols.

According to the life-cycle evaluation, the generation of biodiesel by enzymatic catalysis was more environmentally friendly, with improvements observed in all effect categories, including acidification, photochemical oxidation and global warming,. Figure 2. shows enzymatic biodiesel production process. Biological catalysis produces more favourable life-cycle assessment outcomes because to its lower pressures and temperatures. Table 3 lists the benefits and drawbacks of utilizing lipase as a catalyst in the transesterification process to produce biodiesel.

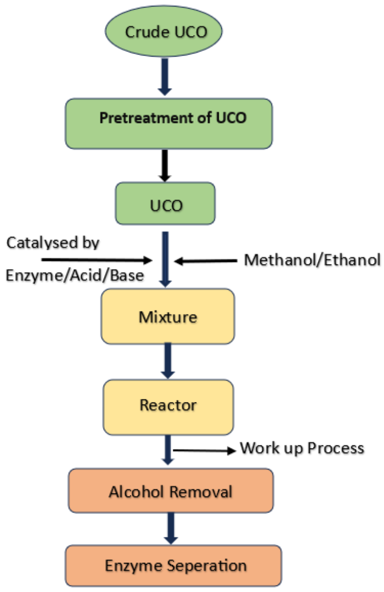

Fig 2. Enzymatic technique for producing biodiesel [55,56,57]

Table 3. The benefits and drawbacks of employing lipases in transesterification [38,48,54]**.**

Benefits	Drawback
Environmentally acceptable, biodegradable, and biocompatible	loss of some early activity due to the amount of the oil molecule
Compared to chemical catalysts, lipases catalyse more precise reactions, resulting in purer products.	Lower alcohols like methanol and ethanol destroy the immobilized lipase.
Because the Immobilized residue may be remained in the reactor as long as the reactive flow is sustained, there is a chance for its regeneration and reuse.	The quantity of support enzymes varies.
Longer lipase activation is made possible by the use of high doses of enzymes in the reactors.	Although the potential prices are decreasing, the manufacture of commercial enzymes is still too expensive.
Lipase immobilization could shield it from potential reaction solvents and keep all of the enzyme particles from clumping together.	Compared to chemical catalysts, lipase activity is comparatively lower.

4. ROLE OF WASTE COOKING OIL BIODIESEL IN CIRCULAR ECONOMY

The circular economy is defined as a system of regeneration with the aim of lowering waste, consumption resource and energy losses, emissions[58]. In order to do this, material and energy cycles are purposefully slowed down, closed, and narrowed. The circular economy model for waste cooking oil, which emphasizes effective recycling, resource management and sustainability to reduce waste and increase usage of resource is depicted in Figure 3. This strategy lowers carbon emissions, waste, and pollution. Utilizing WCO as a renewable raw material presents a significant opportunity. It is anticipated that WCO production from residential and commercial sources will exceed annually worldwide. The European Union (EU) provides around 1 million tons per year in this regard [59]. Creating effective WCO collecting systems contributes to a reliable supply of feedstock.

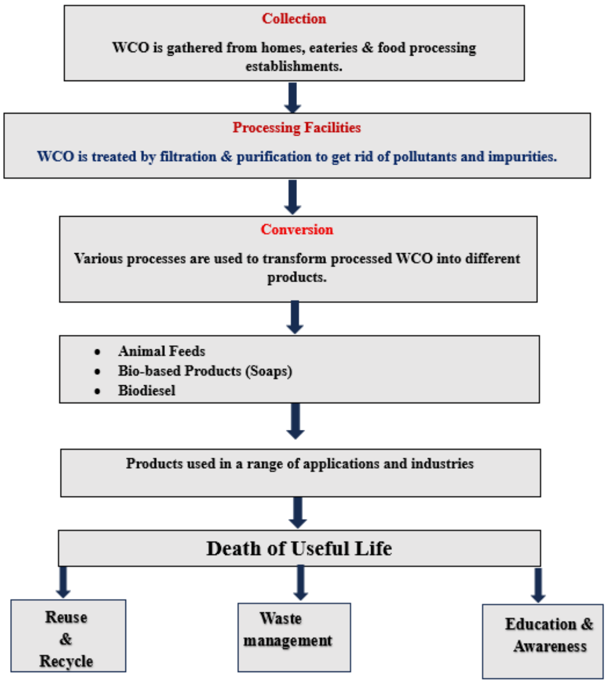

Fig 3. Waste cooking oil (WCO) circular economy schematic block diagram

5. FUTURE PERSPECTIVE

Waste cooking oil has a promising future in sustainable energy and the circular economy. To reach their full potential and help create a more resource-efficient and environmentally friendly future, they must overcome obstacles and take advantage of opportunities. Future technology advancements and production growth will be key factors in unleashing the potential of used cooking oils for the circular economy and sustainable energy production. Over time, improvements in waste management techniques and biofuel production processes will increase cost-effectiveness and efficiency. Additionally, programs for the recycling of spent cooking oils will be introduced and investments will be encouraged by supportive national and international policies. Integration into models of the circular economy maximizes value, reduces waste, and optimizes resource utilization. The economics of WCO recycling will be enhanced by expanding applications beyond the generation of biofuel, such as bio-plastics and cosmetics. While further innovation and research will propel greater advancements in applications and technology, public awareness and education efforts will be crucial in fostering wider acceptance. Used cooking oils will significantly contribute to sustainable energy and environmental protection, so overall, the future looks bright.

6. CONCLUSION

Compared to other procedures, the enzymatic transesterification process has additional benefits: there is little to no need for pretreatment, and the catalysts, or enzymes, are ecologically friendly. The operating conditions are generally ambient and moderate before transesterification. Additionally, the grade of the by-product glycerin is decent (greater than 90% purity), which will add an additional source of revenue for the company, and the ratio of alcohol to oil is lower than prior approaches, which can cut the cost of production. Additionally, using waste cooking oils (WCOs) as a raw material for biodiesel is a creative way to achieve a more sustainable and circular energy production. Recycling WCOs can help produce efficient and ecologically beneficial biodiesel, which is consistent with the circular economy's tenets. Because of its lower greenhouse gas emissions, cost, and ability to meet fuel requirements, it is a feasible substitute for fossil fuels. WCO-based biodiesel reduces the environmental impact by converting waste into energy. Despite the challenges, ongoing research promises the optimization of WCO-based biodiesel and the potential for a cleaner, more circular future.

REFERENCES

1. Gumbo L, Chude-Okonkwo U. Implications of the Just Energy Transition on Rural Economies in Africa. Acta Universitatis Danubius. Œconomica. 20;21**(5)**:66-83 **(2025)**
2. ASTM D6751-08- Standard specification for biodiesel fuel (B100) blend stock for distillate fuels, In: Annual Book of ASTM Standards, ASTM International, West Conshohocken, Method D6751-08, 2008a.
3. Ziolkowska, J.R., Biofuels technologies: An overview of feedstocks, processes, and technologies. *Biofuels for a more sustainable future*, pp.1-19 **(2020)**
4. Malode, S.J., Gaddi, S.A.M., Kamble, P.J., Nalwad, A.A., Muddapur, U.M. and Shetti, N.P., Recent evolutionary trends in the production of

biofuels. *Materials Science for Energy Technologies*, ***5***, pp.262-277 **(2022)**

5. Maliha, A. and Abu-Hijleh, B., A review on the current status and post-pandemic prospects of third-generation biofuels. *Energy systems*, ***14***(**4**), pp.1185-1216 **(2023)**
6. Powar, R.S., Yadav, A.S., Ramakrishna, C.S., Patel, S., Mohan, M., Sakharwade, S.G., Choubey, M., Ansu, A.K. and Sharma, A., Algae: A potential feedstock for third generation biofuel. *Materials Today: Proceedings*, ***63***, pp. A27-A33 **(2022)**
7. Veluru, S., Hamzah, H.T., Tukaram, B.M., Poiba, V.R. and Mahdi, H.S., A review on biodiesel production from various feedstocks by transesterification. In *IOP Conference Series: Materials Science and Engineering* (**Vol. 1258**, No. 1, p. 012024). IOP Publishing **(2022)**
8. Singh, D., Sharma, D., Soni, S.L., Sharma, S., Sharma, P.K. and Jhalani, A., A review on feedstocks, production processes, and yield for different generations of biodiesel. *Fuel*, ***262*,** p.116553 **(2020)**
9. Paschalidou, A., Tsatiris, M. and Kitikidou, K., Energy crops for biofuel production or for food?-SWOT analysis (case study: Greece). *Renewable Energy*, ***93***, pp.636-647 **(2016)**
10. Adenuga, A.A., Oyekunle, J.A.O. and Idowu, O.O., Pathway to reduce free fatty acid formation in Calophyllum inophyllum kernel oil: A renewable feedstock for biodiesel production. *Journal of cleaner production*, ***316*,** p.128222 **(2021)**
11. Athar, M. and Zaidi, S., A review of the feedstocks, catalysts, and intensification techniques for sustainable biodiesel production. *Journal of Environmental Chemical Engineering*, ***8***(**6**), p.104523 **(2020)**
12. Awogbemi, O., Von Kallon, D.V., Aigbodion, V.S. and Panda, S., Advances in biotechnological applications of waste cooking oil. *Case Studies in Chemical and Environmental Engineering*, ***4***, p.100158 **(2021)**
13. Khan, H.M., Iqbal, T., Yasin, S., Irfan, M., Kazmi, M., Fayaz, H., Mujtaba, M.A., Ali, C.H., Kalam, M.A., Soudagar, M.E.M. and Ullah, N., Production and utilization aspects of waste cooking oil based biodiesel in Pakistan. *Alexandria Engineering Journal*, ***60***(**6**)**,** pp.5831-5849 **(2021)**
14. Teixeira, M.R., Nogueira, R. and Nunes, L.M., Quantitative assessment of the valorisation of used cooking oils in 23 countries. *Waste management*, ***78***, pp.611-620 **(2018)**
15. Yusuff, A.S., Adeniyi, O.D., Olutoye, M.A. and Akpan, U.G., Waste Frying Oil as a Feedstock for Biodiesel. Petroleum Chemicals: Recent Insight**, 2**, pp.5-29 **(2019)**
16. Topi, D.,Transforming waste vegetable oils to biodiesel, establishing of a waste oil management system in Albania. *SN Applied Sciences*, ***2***(**4**)**,** p.513 **(2020)**
17. Sarno, M. and Iuliano, M., Biodiesel production from waste cooking oil. *Green Processing and Synthesis*, ***8***(**1**)**,** pp.828-836 **(2019)**
18. Casallas, I.D., Carvajal, E., Mahecha, E., Castrillon, C., Gomez, H., Lopez, C. and Malagon-Romero, D.,Pre-treatment of waste cooking oils for biodiesel production. *Chemical Engineering Transactions*, ***65*,** pp.385-390 **(2018)**
19. Saini, R.D., Conversion of waste cooking oil to biodiesel. *International Journal of Petroleum Science and Technology*, ***11***(**1**), pp.9-21 **(2017)**
20. Math, M.C., Kumar, S.P. and Chetty, S.V., Technologies for biodiesel production from used cooking oil—A review. *Energy for sustainable Development*, ***14***(**4**)**,** pp.339-345 **(2010)**
21. Maddikeri, G.L., Pandit, A.B. and Gogate, P.R., 2012. Intensification approaches for biodiesel synthesis from waste cooking oil: a review. *Industrial & Engineering Chemistry Research*, ***51***(**45**), pp.14610-14628 **(2012)**
22. Statista (2023). Global production of vegetable oils from 2000/01 to 2022/23 (in million metric tons), Statista Research Department. https://www.statista.com/statistics/263978/global-vegetable-oil-production-since-20002001/. Assessed Online 24/08/2023 at 9.30am
23. EUBIA - The European Biomass Industry Association (2015). Transformation of used cooking oil into biodiesel: from waste to resource, Technical Report of European Biomass Industry Association. 1-8.
24. Mannu, A., Ferro, M., Pietro, M.E.D. and Mele, A., Innovative applications of waste cooking oil as raw material. *Science progress*, ***102***(**2**)**,** pp.153-160 **(2019)**
25. Ma, F. and Hanna, M.A., Biodiesel production: a review. *Bioresource technology*, ***70***(**1**), pp.1-15 **(1999)**
26. Demirbaş, A.,Conversion of biomass using glycerin to liquid fuel for blending gasoline as alternative engine fuel. *Energy Conversion and Management*, ***41***(**16**), pp.1741-1748 **(2000)**
27. Antolın, G., Tinaut, F.V., Briceno, Y., Castano, V., Perez, C. and Ramırez, A.I., Optimisation of biodiesel production by sunflower oil transesterification. *Bioresource technology*, ***83***(**2**)**,** pp.111-114 **(2002)**
28. Barnwal, B.K. and Sharma, M.P., Prospects of biodiesel production from vegetable oils in India. *Renewable and sustainable energy reviews*, ***9***(**4**), pp.363-378 **(2005)**
29. Meher, L.C., Sagar, D.V. and Naik, S.N., Technical aspects of biodiesel production by transesterification—a review. *Renewable and sustainable energy reviews*, ***10***(**3**), pp.248-268 **(2006)**
30. Du, W., Xu, Y., Liu, D. and Zeng, J., Comparative study on lipase-catalyzed transformation of soybean oil for biodiesel production with different acyl

acceptors. *Journal of Molecular Catalysis B: Enzymatic*, ***30*****(3-4)**, pp.125-129 **(2004)**

31. Hama, S., Yamaji, H., Kaieda, M., Oda, M., Kondo, A. and Fukuda, H., Effect of fatty acid membrane composition on whole-cell biocatalysts for biodiesel-fuel production. *Biochemical Engineering Journal*, ***21*****(2),** pp.155-160 **(2004)**
32. Noureddini, H., Gao, X. and Philkana, R.S., 2005. Immobilized Pseudomonas cepacia lipase for biodiesel fuel production from soybean oil. *Bioresource technology*, ***96*****(7)**, pp.769-777 **(2005)**
33. Oda, M., Kaieda, M., Hama, S., Yamaji, H., Kondo, A., Izumoto, E. and Fukuda, H., Facilitatory effect of immobilized lipase-producing Rhizopus oryzae cells on acyl migration in biodiesel-fuel production. *Biochemical Engineering Journal*, ***23*****(1),** pp.45-51 **(2005)**
34. Shieh, C.J., Liao, H.F. and Lee, C.C., Optimization of lipase-catalyzed biodiesel by response surface methodology. *Bioresource technology*, ***88*****(2),** pp.103-106 **(2003)**
35. Zhang, Y., Dube, M.A., McLean, D.D.L. and Kates, M., Biodiesel production from waste cooking oil: 1. Process design and technological assessment. *Bioresource technology*, ***89*****(1),** pp.1-16 **(2003)**
36. Meher, L.C., Sagar, D.V. and Naik, S.N.,Technical aspects of biodiesel production by transesterification—a review. *Renewable and sustainable energy reviews*, ***10*****(3)**, pp.248-268 **(2006)**
37. Demirbaş, A., Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods: a survey. *Energy conversion and Management*, ***44*****(13)**, pp.2093-2109 **(2003)**
38. Marchetti, J.M., Miguel, V.U. and Errazu, A.F.,Possible methods for biodiesel production. *Renewable and sustainable energy reviews*, ***11*****(6)**, pp.1300-1311 **(2007)**
39. Agarwal, A.K., Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Progress in energy and combustion science*, ***33*****(3),** pp.233-271 **(2007)**
40. Haas, M., The interplay between feedstock quality and esterification technology in biodiesel production. *Lipid Technology*, ***16*****(1),** pp.7-10 **(2004)**
41. Demirbas, A., Biodiesel production from vegetable oils via catalytic and non-catalytic supercritical methanol transesterification methods. *Progress in energy and combustion science*, ***31*****(5-6)**, pp.466-487 **(2005)**
42. Freedman, B., Butterfield, R.O. and Pryde, E.H., Transesterification kinetics of soybean oil 1. *Journal of the American oil chemists' society*, ***63*****(10)**, pp.1375-1380 **(1986)**
43. Zhang, Y., Dubé, M.A., McLean, D.D. and Kates, M., Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis. *Bioresource technology*, ***90*****(3),** pp.229-240 **(2003)**
44. Devanesan, M.G., Viruthagiri, T. and Sugumar, N.,Transesterification of Jatropha oil using immobilized Pseudomonas fluorescens. *African Journal of biotechnology*, ***6*****(21) (2007)**
45. Iso, M., Chen, B., Eguchi, M., Kudo, T. and Shrestha, S., Production of biodiesel fuel from triglycerides and alcohol using immobilized lipase. *Journal of Molecular Catalysis B: Enzymatic*, ***16*****(1)**, pp.53-58 **(2001)**
46. Köse, Ö., Tüter, M. and Aksoy, H.A., Immobilized Candida antarctica lipase-catalyzed alcoholysis of cotton seed oil in a solvent-free medium. *Bioresource technology*, ***83*****(2)**, pp.125-129 **(2002)**
47. Crabbe, E., Nolasco-Hipolito, C., Kobayashi, G., Sonomoto, K. and Ishizaki, A., Biodiesel production from crude palm oil and evaluation of butanol extraction and fuel properties. *Process biochemistry*, ***37*****(1),** pp.65-71 **(2001)**
48. Chen, J.W. and Wu, W.T., Regeneration of immobilized Candida antarctica lipase for transesterification. *Journal of bioscience and bioengineering*, ***95*****(5),** pp.466-469 **(2003)**
49. Watanabe, Y., Shimada, Y., Sugihara, A., Noda, H., Fukuda, H. and Tominaga, Y., Continuous production of biodiesel fuel from vegetable oil using immobilized Candida antarctica lipase. *Journal of the American Oil Chemists' Society*, ***77*****(4),** pp.355-360 **(2000)**
50. Canakci, M., 2007. The potential of restaurant waste lipids as biodiesel feedstocks. *Bioresource technology*, ***98*****(1)**, pp.183-190 **(2007)**
51. Hsu, A.F., Jones, K.C., Foglia, T.A. and Marmer, W.N., 2003. Optimization of alkyl ester production from grease using a phyllosilicate sol-gel immobilized lipase. *Biotechnology Letters*, ***25*****(20)**, pp.1713-1716 **(2003)**
52. Nelson, L.A., Foglia, T.A. and Marmer, W.N., Lipase-catalyzed production of biodiesel. *Journal of the American Oil Chemists' Society*, ***73*****(9),** pp.1191-1195 **(1996)**
53. Rivera, I., Mateos, J.C. and Sandoval, G., Efficient immobilized lipases for biodiesel synthesis from waste lipids. *Journal of Biotechnology*, ***131*****(2)**, p.S265 **(2007)**
54. Fukuda, H., Hama, S., Tamalampudi, S. and Noda, H., Whole-cell biocatalysts for biodiesel fuel production. *Trends in Biotechnology*, ***26*****(12)**, pp.668-673 **(2008)**
55. Gurunathan, B. and Ravi, A., Biodiesel production from waste cooking oil using copper doped zinc oxide nanocomposite as heterogeneous catalyst. *Bioresource technology*, ***188*****,** pp.124-127 **(2015)**
56. Sebastian, J., Muraleedharan, C. and Santhiagu, A., A comparative study between chemical and enzymatic transesterification of high free fatty acid

contained rubber seed oil for biodiesel production. *Cogent Engineering*, ***3*****(1),** p.1178370 **(2016)**

57. Sotoft, L.F., Rong, B.G., Christensen, K.V. and Norddahl, B., Process simulation and economical evaluation of enzymatic biodiesel production plant. *Bioresource Technology*, ***101*****(14)**, pp.5266-5274 **(2010)**
58. Geissdoerfer, M., Savaget, P., Bocken, N.M. and Hultink, E.J., The Circular Economy–A new sustainability paradigm?. *Journal of cleaner production*, ***143*****,** pp.757-768 **(2017)**
59. Cho, S., Kim, J., Park, H.C. and Heo, E., Incentives for waste cooking oil collection in South Korea: a contingent valuation approach. *Resources, Conservation and Recycling*, ***99*****,** pp.63-71 **(2015)**