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PROSPECTS OF SESAME SEED OIL FOR BIO-DIESEL PRODUCTION: SHORT REVIEW

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ABSTRACT

The use of petroleum based fuel is increasing rapidly with global industrialization and modernization that creates severe issue of energy crises and environmental deterioration. The rapid consumption of petroleum based fuel may cause the depletion of fossil fuel reserves that are world's primary energy resource. The rapid use of fossil fuel in transport purpose may cause the various types of pollutants in the environment and the earth's natural environment changing constantly. Now we need to explore renewable energy resource as alternative source of fossil fuel energy. In such situation bio-diesel as a renewable energy resource has become more attractive for last two decades. The low emission of pollutants from bio-diesel fuel makes it environmentally acceptable by many countries. Among the various feed stock of vegetable oil, the sesame seed oil is potential feed stock for the production of bio-diesel as it has unique physicochemical properties than other vegetable oil. The opportunities of biodiesel production from sesame seed oil is now more challenging worldwide.
Keywords: Sesame seed oil, alternative fuel, biodiesel, trans- esterification, cetane number.

INTRODUCTION

The demand of energy in transport sector is gradually increasing which causes the gradual decline of fossil fuel reserves (Wakil *et al.*, 2015b). The rapid uses of fossil fuel releases toxic gases so called nitrogen oxide (NO_X), carbon monoxide (CO), unburned hydrocarbons and unseen particulate matters that are related to cause the global warming as well as several human diseases (Aransiola *et al*., 2014). It has been shown that about 98% carbon emissions is occurred from the combustion of fossil fuel (Balat 2010).

The energy is obtained from various sources such as modern sources of renewable energy (10.4%), energy in traditional biomass (7.8%), nuclear energy (2.2%) and energy from fossil fuel(79.5%). Among these the transport sector needs approximately 50% of total fossil fuel consumption based energy (2018). In this context the renewable and sustainable fuel can reduce the dependency on fossil fuel. As the Global Status Report (2018) shows the use of renewable energy in transport sector may be 40% in 2030 that is national target of developed countries (2018), so the use of bio-diesel as an alternative fuel is very promising.

Bio-diesel can be obtained from virgin vegetable oil or from waste animal fats and oils that may be used alone or blending with petroleum diesel (Meher *et al*., 2006).

The use of bio-diesel as an alternative fuel is most suitable than fossil fuel as the bio-diesel contains good physicochemical characteristics (Patel and Sankhava, 2017). So many studies have been done for the production of bio-diesel from several feed stocks such as soybean oil (Aransiola *et al*., 2010), Camelina oil (Wu, 2011), neem oil (Muthu *et al*., 2010, Aransiola *et al*., 2012), Karanja oil (Meher *et al*., 2006), sesame oil (Saydut *et al.,* 2008) and Palm Oil (Margaretha *et al*., 2012).

In Asia, Europe and in the United States the bio-diesels are prepared from Soybean, Palm and Rapeseed oil (Silitonga *et al.,* 2013). The use of corn and sugarcane for the production of biofuel creates shortage in food production (Silitonga *et al.,* 2019).

The bio-diesel which is nontoxic containing high cetane number with good lubricity and low sulphur content is better for use (Wakil *et al*., 2015b; Imdabul *et al*., 2016). The vegetable oil which contains high percentage of monounsaturated fatty acids with low proportion of polyunsaturated fatty acid that is good for the bio-diesel production (Wang *et al*., 2011). So the selection of feed stock is crucial for the production of vegetable oil. The sesame seed oil is suitable because it has high oxidative stability for the presence of sesamin, sesamol and sesamolin (anti-oxidants) and vitamin E (tocopherol) and the sesame seed oil also shows high degree of unsaturation with better cold flow properties (Pullen and Saeed, 2014). The most significant nature of SSO is its resistance to oxidation due to the presence of sesamolin, sesamin, lignins (Lee *et al*., 2008) the emission of NO_X is low in case of sesame biodiesel compared to other biodiesels. The sesame seed oil has become more attractive for bio-diesel production because of its environmental benefits and energy security (Mujtaba *et al.,* 2020).

History, cultivation and production of Sesame seed

Sesame (*Sesamum indicum L*) commonly known as til in Asia and as benni seed in Africa (Amoo *et al.,* 2017). Sesame cultivation has been started in South Asia before

2000 BC during Harappan Civilization time (Fuller 2003). Sesame is most valuable oil producing crop. The sesame seeds consumed mainly for its high quality food value as it contains oil nearly 44-57%, protein 18-25% and carbohydrate 13-14% (Borchani *et al*., 2010). Sesame seeds rich in carbohydrate, protein and various nutrients such as Ca, Zn, Fe (Aglave, 2018). Obiajunwa *et al*. (2005) carefully studied the sesame seeds and reported that the sesame seeds contain calcium (Ca), phosphorus (P), manganese (Mn), zinc (Zn), copper (Cu) and iron (Fe). Actually Fe plays important role in body's energy metabolism and in the maintenance of immunity systems (Roeser, 1986).

This oil seed crophas been grown throughout tropics and sub-tropical regions (Zhang *et al*., 2013). The sesame belong to the family Pedaliaceae with 38 species are known (Kobayashi, 1991). This oilseed crop has been grown in tropical, sub-tropical region. Sesame is cultivated in India, China, South America and Africa (Chakraborty *et al*., 2008). In respect to oil production the position of sesame is 8^{th} among the other oil seed crops (Mehmood *et al*., 2018). The sesame oil contains fatty acids such as oleic acid 32.7-53.9%, linoleic acid 39.3-59.0%, palmitic acid 8.3-10.9% and stearic acid 3.4-6.0% (Yermanons *et al*., 1972). The composition of fatty acids of sesame seed oil mainly varies within the different types of sesame varieties (Brar, 1942). The developing countries produce more sesame than the developed countries. Actually half of the world's sesame production have been shown in Asia then followed by Africa (Islam *et al*., 2016). Japan imports highest sesame seeds, followed by China though produces maximum sesame seeds. USA, Canada and Turkey also import sesame seeds (Sharaby and Butovchenko 2019). The sesame has been cultivated in many countries such as Myanmar, India, Nigeria, Sudan, Uganda, China, Ethiopia, south Sudan and also in Tanzania (Mujtaba *et al*., 2020).

According to the Food and Agricultural Organization of the United Nations (FAOSTAT, 2018), the productions of sesame seeds in Africa, Asia and America were 3.14 million, 2.19 million and 0.189 million tons. Among the various oilseed crops like soybean, groundnut, linseed, sunflower, rapeseed, the production of sesame in the world is around 5,532,000 metric tons (FAOSTAT, 2020).

Uses of sesame seeds and its oil

The literature shows use of sesame oil since Vedic times and in ayurveda it was popular for its healing properties that used in Tibetan medicine (Tinay *et al*., 1976; Mozzami and Eldin, 2006). The sesame oil has been applied to the abdomen region to reduce the pain related with premenstrual syndrome PMS (Tinay *et al*., 1976).

The sesame seed contains tocopherol being natural antioxidant that can prevent the oil from oxidation and it is a good source of vitamin E (Brigelius *et al*., 2002). The sesame oil used as cooking oil in many countries. As the sesame seed having antioxidant properties it is used in food industries. The sesame seed can be applied in the preparation of various recipes such as sesame broccoli rice, ginger sesame chicken. The presence of sesamin and sesamolin of sesame enhance the oxidation rate of both hepatic mitochondrial and peroxisomal fatty acid and the vitamin E of sesame seed can protect from heart disease and cancer (Noon, 2003). The major lignans presents in the sesame seed having the unique characteristics which can reduce the level of arachidonic acid and blood lipids (Shimizu *et al*., 1991). Sesame seeds are also used for the preparation of different types of sweets (Pathak *et al.,* 2004). The sesame seeds are used to prepare bread, confections and tahini an oily paste (Prithviraj and Parameshwarappa, 2017).

The sesame seed oil has been applied for the treatment of coughs, migraines, tuberculosis, burns and in eye diseases (Hedge, 2012). Sesame seeds being a good source of calcium, phosphorus and iron and also full of vitamin B, E and it also contain trace elements in small amount (Lyon 1972; Bedigian *et al.,* 1985).

Trans-esterification of Sesame Oil :

The trans-esterification is a process that involves the reaction of a triglyceride with an alcohol to get glycerol and esters. Several researches (Betiku and Adepoju, 2013; Karim *et al.,* 2014; Dawodu *et al*., 2014; Wakil *et al*., 2014) conducted the trans esterification process of sesame seed oil through the use of homogenous base catalyst (KOH, NaOH, CH_3ONa). It is the conversation of triglyceride into a mono-alkyl esteri.e bio-diesel and glycerol where alcohol used as a catalyst (Demirbas, 2005). The steps of trans esterification of vegetable oil to get biodiesel followed by (Karim *et al.,* 2014) are given here :

$$\text{Triglyceride} + \text{ROH} \longleftrightarrow \text{Diglyceride} + \text{RCOOR}_1$$

$$\text{Diglyceride} + \text{ROH} \longleftrightarrow \text{Monoglyceride} + \text{RCOOR}_2$$

$$\text{Monoglyceride} + \text{ROH} \longleftrightarrow \text{Glycerol} + \text{RCOOR}_3$$

R_1, R_2, and R_3 denotes any alkyl hydrocarbon chain.

The utility of the trans-esterification is to reduce the viscosity of the oil. The use of ethanol in trans-esterification is more preferable than any other alcohol as ethanol is obtained from agricultural products (Dias *et al*., 2012).

The sesame oil being most resistant towards oxidation rancidity that the other vegetable oil and this high resistance is due to presence of natural oxidants i.e. sesamine, sesamol, sesamolin (0.3-0.5%) and tocopherols (0.5-1.0%) (Hedge, 2012). The transesterification of sesame seed oil may be done by the use of heterogeneous catalyst $Ba(OH)_2$ through ultrasound-assisted trans-esterification that generated a maximum optimized biodiesel (Sarve *et al*., 2015). The base-catalyzed reaction was conducted by Schinas *et al.* (2009).

For the production of biodiesel sesame seed oil is most useful potential feed stock and it is reported the trans-esterification of Turkey and Pakistan cultivars of sesame oil has been conducted to get bio-diesel (Saydut *et al.*, 2008; Ahmed *et al*., 2010; Ahmed *et al*., 2011). Betiku and Adepoju (2013) made an effort for trans-esterification of sesame seed oil from a Nigeria cultivar to get bio-diesel.

The cost of bio-diesel is high as the high quality virgin oil is used for the production of bio-diesel so the use of bio-diesel in the developing countries could not extended like developed countries (Bhatti *et al*., 2008). Actually fuels that are used in transport vehicles releases black smoke particulate with SO_2, which generates greenhouse gases (Phan and Phan, 2008). The high oxygen content of bio-diesel fuel and its use can reduce the release of carbon monoxide, sulfur, poly-aromatics, hydrocarbons and also the particulate matter. The bio-diesel is obtained from plant materials which does not increase the net atmospheric CO_2 level. The use of feed stock like as waste frying oil and non-

edible oil may also use to produce bio-diesel (Yahyaee *et al*., 2013).

Standards of Bio-diesel

The optimization of the trans-esterification process of sesame oil to bio-diesel is very significant to determine the purity of bio-diesel and the use of Response Surface Methodology (RSM) software is best the option for the analysis of sesame bio-diesel (Shanmuga prakash and Sivakumar, 2013). The determination of bio-diesel fuel properties is followed the standard methods and compared with American and European Standards (ASTMD6751 and DIN EN14214) (Atabani *et al*., 2012).

Properties of Sesame Seed Oil based Bio-Diesel

The quality of bio-diesel fuel is checked by the cetane number (CN) that is a measure of ignition quality of diesel fuel. In case of bio-diesel the CN is higher than the petro-diesel due to the presence of high oxygen content in bio-diesel (Karim *et al*., 2014). The literature shows the addition of alcohol-based additives like methanol, ethanol etc. in very small quantity may improve the cetane number for bio-diesel fuel and also in blended fuel (Ali *et al*., 2016; Yasin *et al*., 2014). Cold flow properties of bio-diesel are very promising in case of sesame seed oil (Wakil *et al*., 2015b). The high degree of unsaturation of sesame seed oil shows best cold flow properties with compared to other vegetable oils.

The flash point of bio-diesel fuel shows higher value in comparison with petro-diesel fuel that is required for safe transport (Ma and Hanna, 1999). Betiku and Adepoju (2013) reported that sesame seed oil shows the sesame bio-diesel contains linoleic acid (45.17%), oleic acid (39.02%), palmitic acid (8.47%), stearic acid (5.15%), arachidic acid (0.77%), linolenic acid (0.15%), palmitoleic acid (0.04%) and erucic acid (0.01%). The unsaturated fatty acid of sesame oil plays a major role in case of oxidative stability of fuel obtained from bio-diesel (Park *et al*., 2008). Due to the presence of natural antioxidants and vitamin E the sesame oil is less susceptible to oxidative rancidity (Gharby *et al*., 2017) as a result the sesame oil is more stable than other vegetable oil.

CONCLUSION

Fossil fuels are world's primary energy source and the energy consumption in various sectors creates depletion in fossil fuel. Fuel is essential in industrial development and growth of any country. If the consumption of petroleum based fuel continues then the resources will be depleted in near future. In this regard as an alternative fuel the use of bio-diesel fuel is very much challenging. Alternative fuels are derived from sources other than petroleum based fuel that reducing our dependency on imported oil. Many experiments have been conducted for the production of bio-diesel from vegetable oil. Among the various feed stocks, the sesame seed oil is very significant (Ferdous *et al*., 2012; Schinas *et al*., 2009). The demand of diesel fuel around 1.0 billion tons globally that is far exceeds the present production of biodiesel from vegetable oil and animal fat. The vegetable oil feedstocks would supply around 10% of the diesel fuel (Xu and Hanna, 2009).

According to Ferdous *et al.* (2012) the bio-diesel derived from sesame seed oil can be compared with standard value of biodiesel and petro-diesel. The sesame seed oil based bio-diesel has unique physicochemical properties that are ideal fuel for use in transport sector. This bio-diesel can be blended with other vegetable oil for the commercial use. The production of bio-diesel in any country can create jobs in the agricultural section and seems to be ideal solution for global energy issue and environmental benefits.

REFERENCES

Aglave, H.R.; 2018. Physiochemical characteristics of sesame seeds. *Journal of Medicinal Plants*, *6*(1), pp.64-66.

Ahmad, M.; Khan, M.A.; Zafar, M. and Sultana, S. (2010). Environment-friendly renewable energy from sesame biodiesel. *Energy Sources* A 32: 189–196.

Ahmad, M.; Ullah, K.; Khan, M.A.; Ali, S.; Zafar, M. and Sultana, S. (2011). Quantitative and qualitative analysis of sesame oil biodiesel, Energy Sources. Part A. 33(13): 1239–1249.

Ali, O.M.; Mamat, R.; Masjuki, H.H. and Abdullah, A.A. (2016). Analysis of blendedfuel properties and cycle-to-cycle variation in a diesel engine with a diethyl ether additive. Energy Convers. Manage. 108: 511–519.

Amoo, S.O.; Okorogbona, A.O.M.; Du Plooy, C.P. and Venter, S.L. (2017). *Sesamum indicm*. In: Medicinal Spices and Vegetables from Africa, 549-579.

Aransiola, E.F.; Betiku, E.; Layokun, S.K. and Solomon, B.O. (2010). Production of biodiesel by trans esterification of refined soybean oil. *Int. J. Biol. Chem. Sci*., 4: 391–399.

Aransiola, E.F.; Betiku, E.; Ikhuomoregbe, D.I.O.; Ojumu, T.V. (2012). Production of biodiesel from crude neem oil feedstock and its emissions from internal combustion engines. *Afr. J. Biotech.* 11(22): 6178–6186.

Aransiola, E.; Ojumu, T.; Oyekola, O.; Madzimbamuto, T. and Ikhu-Omoregbe, D. (2014). A review of current technology for biodiesel production: State of the art. *Biomass Bioenergy*, 61: 276–297.

Atabani, A.E.; Silitonga, A.S.; Badruddin, I.A.; Mahlia, T.; Masjuki, H. and Mekhilef, S. (2012). A comprehensive review on biodiesel as an alternative energy resource and its characteristics. Renew. Sustain. *Energy Rev*., 16: 2070–2093.

Balat, M. (2010). Potential alternatives to edible oils for biodiesel production – a review of current work. *Energ. Convers. Manage*. 52: 1479–1492.

Bedigian, D.; Seigler, D.S. and Harlan, J.R. (1985). Sesamin, sesamolin and the origin of sesame. *Biochem. Syst. Ecol*. 13: 133–139.

Betiku, E. and Adepoju, T.F. (2013). Methanolysis optimization of sesame (*Sesamum indicum*) oil to biodiesel and fuel quality characterization. *Int. J. Energy Environ. Eng*. 4: 9.

Bhatti, H.N.; Hanif, M.A. and Qasim, M. (2008). Biodiesel production from waste tallow. Fuel, 87(13): 2961-2966.

Borchani, C.; Besbes, S.; Blecker, C. and Attia, H. (2010). Chemical characteristics and oxidative stability of sesame seed, sesame paste, and olive oils.

Brar, G.S. (1982). Variations and correlations in oil content and fatty acid composition of sesame. *Ind. J. Agric. Sci*. 52: 434–439.

Brigelius-Flohe, R.; Kelly, F.J.; Salonen, J.T.; Neuzil, J.; Zingg, J.M. and Azzi, A. (2002). The European

perspective on vitamin E: Current knowledge and future research. *Am J Clin. Nutr*. 76: 703-716.

Chakraborthy, G.S.; Sharma, G. and Kaushik, K.N. (2008). *Sesamum indicum*: A Review. *Journal of Herbal Medicine and Toxicology*, 2(2): 15-19.

Dawodu, F.A.; Ayodele, O.O. and Bolanle-Ojo, T. (2014). Biodiesel production from *Sesamum indicum* L. seed oil: An optimization study. *Egypt. J. Pet.*, 23:191–199.

Demirbas, A. (2005). Biodiesel production from vegetable oils via catalytic and non-catalytic supercritical methanol trans esterification methods. *Prog. Energy Combust. Sci*. 31: 466–487.

Dias, J.M. (2012). Selection of heterogenous catalyst for biodiesel production from animal fat. Fuel, 94: 418-425.

FAO (2018). Food and agricultural organization of the United Nations (FAO) report.

Ferdous, K.; Uddin, M.R.; Khan, M.R. and Islam, M. (2012). Biodiesel from Sesame oil: Base catalysed transesterification. Int. J. Eng. Technol. 1: 420–431.

Food and Agriculturre Organization Statistical Databases (FAOSTAT). Available online: http://faostat.fao.org/ (accessed on 5 February 2020).

Fuller, D.Q. (2003). Further evidence on the prehistory of sesame. Asian Agri-Hist. 7: 127–137.

Gharby, S.; Harhar, H.; Bouzoubaa, Z.; Asdadi, A.; El-Yadini, A. and Charrouf, Z. (2017). Chemical characterization and oxidative stability of seeds and oil of sesame grown in Morocco. *J. Saudi Soc. Agric. Sci*. 16: 105–111.

Renewables (2018). Global Status Report. REN 21 Secretariat, Paris, 2018.

Hegde, D.M. (2012). Sesame. In: Hand Book of Herbs and Spices. pp. 449–486.

Imdadul, H.K.; Masjuki, H.H.; Kalam, M.A.; Zulkifli, N.W.M.; Alabdulkarem, A. and Rashed, M.M. (2016). Higher alcohol–biodiesel–diesel blends: An approach for improving the performance, emission, and combustion of a light-duty diesel engine. *Energy Convers. Manage*. 111: 174–185.

Islam, F.; Gill, R.A.; Ali, B.; Farooq, M.A.; Xu, L. and Najeeb, U. (2016). Sesame.In: Breeding Oilseed Crops for Sustainable Production. 135–147.

Karim, A.; Younis, J.L.G. and Barzinji, Kasim S. (2014). Production and characterization of biodiesel from locally sourced sesame seed oil, used cooking oil and other commercial vegetable oils in erbil-iraqikurdistan. *Amer. J. Appl. Chem*. 2: 105–111.

Kobayashi, T. (1991). Cytogenetics of sesame (*Sesamum indicum*). In: Chromosome engineering in plants: Genetics, breeding, evolution. Tsuchiya, T.; Gupta, R.K. (Eds.*). Elsevier Science Publishing Company Inc. Amesterdam*. : 581-592.

Lee, J.; Lee, Y. and Choe, E. (2008). Effects of sesamol, sesamin, and sesamolin extracted from roasted sesame oil on the thermal oxidation of methyl linoleate. *LWT-Food Sci. Technol*. 41: 1871–1875.

Lyon, C.K. (1972). Sesame: Current knowledge of composition and use. *J. Am. Oil Chem. Soc.*, 49: 245–249.

Ma, F. and Hanna, M.A. (1999). Biodiesel production: a review1journal series #12109, agricultural research division, institute of agriculture and natural resources, University of Nebraska–Lincoln.1. *Bioresour. Technol*. 70: 1–15.

Margaretha, Y.Y.; Prastyo, H.S.; Ayucitra, A. and Ismadji, S (2012). Calcium oxide from Pomacea sp. shell as a catalyst for biodiesel production. *Int. J. Energy Env. Eng*., 3: 33.

Meher, L.C.; Dharmagadda, V.S.S. and Naik, S.N. (2006). Optimization of alkali-catalyzed trans esterification of *Pongamia pinnata* oil for production of biodiesel. *Bioresour Technol*, 97(12): 1392–1397.

Mehmood, S.; Saeed, D.A.; Rizwan, M.; Khan, M.N.; Aziz, O.; Bashir, S. (2018). Impact of different amendments on biochemical responses of sesame (*Sesamum indicum* L.) plants grown in lead-cadmium contaminated soil. *Plant Physiol. Biochem*. 132: 345–355.

Moazzami, A.A. and Kamal-Eldin, A. (2006) Sesame seed is a rich source of dietary lignans. *J Am Oil Chem. Soc.,* 83: 719-723.

Mujtaba, M.A.; Muk Cho, H.; Masjuki, H.H.; Kalam, M.A.; Ong, H.C.; Gul, M.; Harith, M.H.; Yusoff, M.N.A.M. (2020). Critical review on sesame seed oil and its methyl ester on cold flow and oxidation stability. *Energy Rep*., 6: 40-54.

Muthu, H.; SathyaSelvabala, V.; Varathachary, T.; KiruphaSelvaraj, D.; Nandagopal, J.; Subramanian, S (2010). Synthesis of biodiesel from neem oil using sulfated zirconia via transesterification. *Braz J Chem Eng.,* 27(4): 601–608.

Noon, D.D. (2003). Sesame Oil Benefits Blood Pressure Cooking Oil Switch May Be High Blood Pressure Treatment, Inter- American Society of Hypertension.

Obiajunwa, E.I.; Adebiyi, F.M. and Omode, P.E. (2005). Determination of essential minerals and trace elements in Nigerian sesame seeds, using TXRF technique. *Pakistan Journal of Nutrition*, 4(6): 393-395.

Park, J.-Y.; Kim, D.-K.; Lee, J.-P.; Park, S.-C.; Kim, Y.-J. and Lee, J.-S. (2008). Blendingeffects of biodiesels on oxidation stability and low temperature flow properties. *Bioresour. Technol*. 99: 1196–1203.

Patel, R.L. and Sankhavara, C.D. (2017). Biodiesel production from Karanja oil and its use in diesel engine: A review. Renew. *Sustain. Energy Rev*., 71: 464–474.

Pathak, N.; Rai, A.K.; Kumari, R.; Thapa, A. and Bhat, K.V. (2014). Sesame crop: an underexploited oilseed holds tremendous potential for enhanced food value. *Agricultural Sciences*, 5(06): p.519.

Phan, A.N. and Phan, T.M. (2008). Biodiesel production from waste cooking oils.Fuel, 87(17): 3490-3496.

Prithviraj, S.K. and Parameshwarappa, S.G. (2017). Genetic variability studies for quantitative traits in germplasm collections of sesame (*Sesamum indicum* L.). *J. Farm Sci*.; 30(2): 149-152.

Pullen, J. and Saeed, K. (2014). Experimental study of the factors affecting the oxidation stability of biodiesel FAME fuels. *Fuel Process. Technol.*, 125: 223–235.

Roeser, H.P. (1986). *Iron. J. Food Nutr*.; 42: 82-92.

Sarve, A.; Sonawane, S.S. and Varma, M.N. (2015). Ultrasound assisted biodieselproduction from sesame (*Sesamum indicum* L.) oil using barium hydroxideas a heterogeneous catalyst: Comparative assessment of prediction abilities between response surface methodology (RSM) and artificial neural network (ANN). *Ultrason. Sonochem*. 26: 218–228.

Saydut, A.; Duz, M.Z.; Kaya, C.; Kafadar, A.B. and Hamamci, C: Transesterified sesame (*Sesamum indicum*

L.) seed oil as a biodiesel fuel. *Bioresour. Technol,* 99(14): 6656–6660.

Schinas, P.; Karavalakis, G.; Davaris, C.; Anastopoulos, G.; Karonis, D.; Zannikos, F.; Stournas, S.; Lois, E: Pumpkin (*Cucurbita pepo* L.) seed oil as an alternative feedstock for the production of biodiesel in Greece. *Biomass Bioenerg*, 33: 44–49.

Shanmugaprakash, M. and Sivakumar, V. (2013). Development of experimental designapproach and ANN-based models for determination of Cr (VI) ions uptakerate from aqueous solution onto the solid biodiesel waste residue. *Bioresour.Technol*. 148: 550-559.

Sharaby, N. and Butovchenko, A. (2019). Cultivation technology of sesame seeds and its production in the world and in Egypt. IOP Conf. Series: *Earth and Environmental Science,* 403: 012093.

Shimizu, S.; Akimoto, K.; Shinmen, Y.; Kawashima, H.; Sugano, M. and Yamada, H. (1991). Sesamin is a potent and specific inhibitor of delta 5 desaturase in polyunsaturated fatty acid biosynthesis. Lipids. 26: 512-6.

Silitonga, A.S.; Mahlia, T.M.I.; Kusumo, F.; Dharma, S.; Sebayang, A.H. and Sembiring, R.W. (2019). Intensification of Reutealistrisperma biodiesel production using infrared radiation: Simulation, optimisation and validation. Renew. *Energy,* 133: 520–527.

Silitonga, A.S.; Masjuki, H.H.; Mahlia, T.M.I.; Ong, H.C.; Chong, W.T. and Boosroh, M.H. (2013). Overview properties of biodiesel diesel blends from edible andnon-edible feedstock. Renew. Sustain. *Energy Rev*. 22: 346–360.

Tinay EI A.H.; Khattab, A.H. and Khidir, M.O. (1976). Protein and oil compositions of sesame seed. *J Am Oil Chem. Soc.,* 53: 648-653.

Wakil, M.A.; Kalam, M.A.; Masjuki, H.H.; Atabani, A.E. and Rizwanul Fattah, I.M. (2015b). Influence of biodiesel blending on physicochemical properties andimportance of mathematical model for predicting the properties of biodieselblend. Energy *Convers. Manage*. 94: 51–67.

Wakil, M.; Kalam, M.; Masjuki, H.; Fattah, I.R. and Masum, B. (2014). Evaluation of ricebran, sesame and moringa oils as feasible sources of biodiesel and the effectof blending on their physicochemical properties. RSC Adv. 4: 56984–56991.

Wang, R.; Hanna, M.A.; Zhou, W-W.; Bhadury, P.S.; Chen, Q.; Song, B-A. and Yang, S. (2011). Production and selected fuel properties of biodiesel from promising non-edible oils: *Euphorbia lathyis* L.; *Sapium sebiferum* L. and *Jatropha curcas* L. *Bioresour. Technol*. 102(2): 1194–1199.

Wu, X. and Leung, D.Y.C. (2011). Optimization of biodiesel production from camelina oil using orthogonal experiment. *Appl. Energy,* 88(11): 3615–3624.

Xu, Y. and Hanna, M. (2009). Synthesis and characterization of hazelnut oil-based biodiesel.Industrial crops and products, 29(2): 473-479.

Yahyaee, R.; Ghobadian, B. and Najafi, G. (2013). Waste fish oil biodiesel as a source of renewable fuel in Iran. *Renewable and Sustainable Energy Reviews*, 17: 312-319.

Yasin, M.M.; Yusaf, T.; Mamat, R. and Yusop, A.F. (2014). Characterization of a dieselengine operating with a small proportion of methanol as a fuel additive inbiodiesel blend. *Appl. Energy,* 114: 865–873.

Yeramanos, D.M.; Hemstreet, S.; Saleeb, W. and Huszar, C.K. (1972). Oil content and composition of the seed in the world collection of sesame introductions. *J. Am. Oil Chem. Soc*., 49: 20–23.

Zhang, H.; Miao, H.; Wei, L.; Li, C.; Zhao, R. and Wang, C. (2013). Genetic Analysis and QTL Mapping of seed Coat Color in Sesame (*Sesamum indicum* L.) Plos ONE, 8: e63898.