Open Access Research Journal of
Engineering and Technology
Journals home page: https://oarjpublication/journals/oarjet/
ISSN: 2783-0128 (Online)

OARJ OPEN ACCESS RESEARCH JOURNALS

(Review Article)

Check for updates

Non-edible vegetable oils as bio-lubricant basestocks: A review

Caleb Abiodun Popoola * and Titus Yusuf Jibatswen

Department of Chemical Engineering, Faculty of Engineering, Federal University Wukari, Nigeria.

Open Access Research Journal of Engineering and Technology, 2024, 06(02), 080–086

Publication history: Received on 07 April 2022; revised on 12 May 2024; accepted on 15 May 2024

Article DOI: https://doi.org/10.53022/oarjet.2024.6.2.0040

Abstract

Bio-lubricants are becoming important alternative to mineral oil based lubricants due to growing international concerns about environmental pollution associated with the use and disposal of mineral oil based lubricants. Vegetable oils are nowadays considered as viable bio-resource and promising candidates for the development of bio-based lubricants. As a result, more than 95% of world bio-lubricant is produced from edible oils such as groundnut oil, rapeseed oil, soybean oil, canola oil, palm oil and palm kernel oil. This has affected price, production, uses and availability of these oils for human consumption and brought serious competition between food and lubricants. It is also believed that large-scale production of bio-lubricant from edible oil may bring global imbalance to food supply and demand market. In order to overcome this devastating phenomenon, researches have shifted focus to non-edible oils which are very economical comparable to edible oils and potentially offer greatest opportunities in the longer term for effective lubricant production. Intensive review of recent research works shows that non-edible vegetable oils have high potential to replace edible ones.

Keywords: Bio-lubricant; Non-edible vegetable oils; Lubrication; Pollution; Biodegradable

1. Introduction

Lubrication is widely known as the means of mitigating wear and friction in surfaces under relative motion. Lubricants are usually incorporated between tribo-pairs for lower friction and reduced wear. They separate the interacting surfaces to reduce friction as well as wear; and to cool the mechanical system of the engine by absorbing part of the generated heat in the contacts. A lubricant, according to Abere (2017)[1] has ability to remove contaminants and heat from tribo-contacts in addition to the ability to reduce wear and friction. Also, they should clean and protect contacting surfaces from corrosion as well as neutralizing acids formed during combustion in internal combustion engine. Automotive lubricants are understood to impact on energy and material conservations and acceptable environmental management. Mehic (2017)[2] listed critical functions perform by lubricants to include lubrication, suspending, cooling, cleaning and protecting metal surfaces in order to increase equipment lifetime. They are the materials used in tribological contacts to separate the peak asperities of contacting surfaces.

Lubricants also provide protection from corrosion, dissipation of heat, exclusion of contaminants, and flushing away of wear products as reported by Jackson (2012) [3]. A lubricant according to Khasbage *et al.* (2016) [4] should have capacity to transport protective chemical to the contacts where they are needed and transport wear particles generated away from where they are generated. Lubricants should remain effective under all driving conditions, short-trip and cold-start conditions. Lubricant additives should be able to relate with sliding surfaces to form anti-wear films because additives are the major enhancer of lubricant performance (Ilie and Covaliu, 2016)[5]. Singh and Suhane (2016)[6] described lubrication as a process of introducing a substance between two relatively close surfaces in relative motion, in order to reduce the friction and wear for optimal operation of the machinery. Lubrication is considered as an essential process for convenient and reliable running of mechanical systems as reported by Sayed *et al.* (2018) [7].

* Corresponding author: C.A. Popoola

Major interest in the development of many types of lubricants that are based on vegetable oils in order to protect the environment against pollution caused by the petroleum (mineral)-based lubricants which are toxic and not readily biodegradable (Syahrullail *et al.,* 2013) [8]. Vegetable oils show some basic physicochemical properties such as lubricity, viscosity and thermal stability that make them suitable for lubricant production. Agrawal *et al.* (2017) [9] observed that vegetable oil based lubricant is becoming more attractive everyday due to its environmental benefits. These oils as reported by Ahmed *et al.* (2014) [10], have a capability to contribute towards the goal of controlling environmental pollution, security and energy independence since they are biodegradable and nontoxic. The increase concerns about health and environment worldwide has improved the use biodegradable products. Syaima *et al.* (2014) [11] listed the major benefits of bio-lubricant which include: renewability, low environmental toxicity and biodegradability as well as its high viscosity index, which makes its viscosity to be virtually stable at constant temperature unlike mineral oil. This makes it to be more preferable than mineral oil based lubricant.

According to Srivastava and Sahai (2013) [12], bio-lubricants possess better properties like renewability, environmentally friendly, biodegradability, non-toxicity, excellent lubricity, high fire point and flash point, high viscosity index, low volatility and low vapour emissions. Abere (2017)[1] and Agrawal *et al.* (2017)[9] concluded that vegetable oils can be used as an alternative to mineral oil or petroleum based lubricant as they provide important environmental benefits with excellent performance in many applications and possesses several advantages which include biodegradability, lower toxicity, lower volatility, higher lubricity, higher flash point and viscosity index. Vegetable oils are nowadays considered as viable bio-resource and promising candidates for the development of bio-based lubricants because they have some basic chemo-physical properties which make them suitable to be used for lubricant.

Bio-lubricants according to Jabal *et al.* (2014) [13] are easy to produce and have better lubricating ability due to a huge amount of unsaturated and polar ester groups components they contained which favourably affected the status during reciprocating sliding. Gulzar (2017) [14] reported many studies that have been done on the use of bio-lubricants in internal combustion engine in which tribological properties of fresh vegetable base oils and mineral base oil were comparable but deviated during engine endurance testing due to poor oxidation stability and the absence of additives in the vegetable oils. Globally, there are over 350 oil bearing crops identified as potential sources for bio-lubricant production as reported by Silitonga *et al.* (2013) [15] and Garces *et al.* (2011) [16].

Singh (2017) [17] reported that various oilseeds are being used for the production of bio-lubricants throughout the world. The availability of these seeds depends on the regional climate, geographical locations, local soil conditions and agricultural practices of any country. Khandelwa and Chauhan (2012) [18] listed many oil plants that are available in nature like jatropha, pongamia, rapeseed, mahua, olive, linseed, palm, palm kernel, soybean, cotton seed, castor, among others which are very economical and easily available in developing countries. The use of a particular oilseed depends upon the availability, price and policy. The strong pressures to avoid the use of edible oils as base oils for lubricants has led to the need to explore and search for more non-edible oilseeds which can be used as raw materials for lubricant production to replace edible vegetable oils and which can establish a new pathway from prospective oilseeds.

2. Science of Bio-lubricant Production

Lubricant consists of additives and base oil. The base oils are most often mineral oils and sometimes synthetic liquids or vegetable oils such as esters, hydrogenated polyolefins, silicones and fluorocarbons are used. Typically lubricants contain about 80 - 90% base oil and the remaining are additives. According to Kalam *et al.* (2012) [19], additives are substances added to the lubricants to enhance their tribological behaviour and performance. The quantities of additives used vary depending on function and type of the lubricant. Additives are added to the base oil to improve already existing properties of the base oil and to add new properties such as anti-wear performance, cleaning or suspending ability and corrosion control to the lubricant (Mehic, 2017) [2]. Chemical modification of fatty acids in vegetable oils according to Owuna *et al.* (2020)[20], enhances their thermal as well as oxidative stability and enables the bio-lubricants to withstand wide range of operating conditions.

Bio-lubricant according to Izah and Ohimain (2013) [21] and Bilal (2013) [22], is mostly produced through esterification and transesterification reactions. The aim of esterification of triglyceride is to reduce the fatty acid of the feedstock. Esterification in bio-lubricant production is a pre-treatment process that involves the reaction of alcohol, acid and triglycerides to form ester and glycerol. This pre-treatment is important to reduce formation of soap throughout the reaction and make easy the extensive handling for separation of glycerol and biodiesel together with removal of catalyst and alkaline wastewater. Transesterification results in production of methyl ester of fatty acid and subsequently purification. The triacylglycerol structure with long fatty acid chains and presence of polar groups in the vegetable oils make them amphiphilic in nature, therefore allowing them to be excellent choice as lubricants and functional fluids.

Bio-lubricants are made up of oils from natural biological and agricultural sources according to Habibullah *et al.* (2014) [23]. These oils have rapid biodegradability, low eco-toxicity, and renewable. The bio-based oils are from synthetic or natural vegetable oil, synthetic or natural animal fats, modified vegetable oil, and mixtures thereof. They are known to exhibit low coefficient of friction, good wear protection, higher viscosities indexes and higher flash points in comparison with mineral oils Abere (2017) [1]. Mineral oil based lubricant is non-biodegradable, highly toxic, non-renewable and causes environmental pollution such as air pollution, soil pollution and water pollution. Most rapidly biodegradable lubricants use saturated as well as unsaturated ester base oils. Some are triglycerides such as jatropha oil, rapeseed oil, neem oil, karanja oil, sandbox oil, and sunflower oil; esters of modified vegetable oils, semi-saturated, trans-esterified ester oils with natural fatty acids. Bio-lubricants are free of sulphur-containing compounds and chemicals harmful to human skin and health. Syahrullail *et al.* (2013) [8] listed some of the benefits of bio-lubricants over mineral oil lubricants include renewability, lower toxicity (low carbon), high viscosity index, good lubricity, high flash point, low evaporative loss, safer and biodegradability.

Abere (2017) [1] and Habibullah *et al.* (2014) [23] reported different classes of lubricant biodegradation which are: primary biodegradation, ultimate biodegradation, readily biodegradation and inherently biodegradation. In primary biodegradation, the chemical structure of the lubricant is altered by microorganisms which lead to change in some measurable properties of the lubricant. Ultimate biodegradation is the level of aerobic degradation obtained when the lubricant is totally converted to CO_2, CH_4, H_2O, mineral salts and biomass by microorganisms. Bio-lubricant biodegradation is classified as being ultimate due to total conversion (100% biodegraded) by microorganisms to produce CO_2, CH_4, H_2O, mineral salts and biomass. In readily biodegradation, at least 60% of the lubricant carbon has been converted to CO_2 in 28 days. Abere (2017) [1] reported that less than 5% of the base oils used in formulating conventional lubricants are readily biodegradable. In inherently biodegradation there is some biodegradation evidence in any biodegradability test.

The main purposes of lubrication according to Owuna *et al.* (2020) [20], are to protect the surfaces from corrosion, reduce oxidation, reduce wear due to contact, to prevent heat loss from the surfaces in contact and as sealing agents against dust, dirt and water. For a bio-lubricant to be adopted as lubricant, it should meet a number of standard performance and environmental requirements such as anti-rust, anti-wear, anti-foam, environmentally friendly, resistance to hydrolysis or capacity to withstand the action of water, centrifuge ability and filterability or capacity to separate insoluble elements. The requirements that made bio-lubricant attractive are high viscosity index, properties of boundary lubrication of the polar ester groups and low volatility. The prevailing trend with bio-lubricants is that their high oleic acid concentrations improve friction and wear performance through formation of monolayers on the surface of metals, mostly ferrous metals.

3. Major non-edible vegetable oils for bio-lubricant production

Selection of vegetable oils for lubrication relies upon the oils having relatively low cost, acceptable low temperature properties, good miscibility and acceptable oxidative and thermal stabilities. The major non-edible oils such as Jatropha, Neem, Karanja, Mahua and Sandbox are comparatively less expensive and have advantage over edible oils for the production of bio-lubricants.

3.1. Jatropha (*Jatropha curcas*) Oil

Jatropha oil is a non-edible vegetable oil obtained from Jatropha seed which contains 35% oil. It is considered non-edible oil due to the presence of toxic esters according to Mohammed *et al.* (2018) [24]. The oil has acid value of 10.37 mg KOH/g, specific gravity of 0.92 g/ml, ash content of 0.09%, density of 917±1 kg/m^3, calorific value of 39.071 MJ/kg, mass fraction for carbon of 76.11 % w/w, hydrogen of 10.52% w/w and oxygen of 11.06% w/w as reported by Golshokouh *et al.* (2013) [25]. Khandelwa and Chauhan (2012) [18] reported the fatty composition of Jatropha oil to be 13.38% palmitic acid, 0.88% patmitoleic acid, 5.44% stearic acid, 45.79% oleic acid, 32.27% linoleic acid, 0.31% lauric acid and 1.93% for others. Bilal (2013) [22] investigated the feasibility of producing bio-lubricant from Jatropha oil by conducting chemical modifications on the Jatropha crude oil. The modification involved improving some of the lubricating properties of the Jatropha oil. The bio-lubricant was subjected to certain property tests to ascertain its applicability as lubricating and found that the bio-lubricant produced is conformed to the ISO VG-46 commercial standards and concluded that the bio-lubricant can favourably serve as substitute for petroleum based lubricants.

Menkiti *et al.* (2017) [26] produced environmentally adapted lubricant from Jatropha oil. In the work, Jatropha oil was studied for the synthesis of trimethylolpropane based bio-lube basestock via chemical transesterification using calcium hydroxide catalyst. The bio-lubricant produced had viscosity of 39.45 cSt and 8.51 cSt at 40°C and 100°C respectively, viscosity index of 204, pour point of -12°C and flash point of 178°C which complied with ISO VG 32 standard. They concluded that the resulting properties indicated that Jatropha oil has a high potential for production of lubricants with slight modifications. Golshokouh *et al.* (2013)[25] studied Jatropha oil as alternative source of lubricant oil. Chemo-physical and tribological properties of the oil such as anti-wear, anti-friction, viscosity index, and flash point were investigated and found that Jatropha oil had a higher lubricant ability compared to hydraulic mineral oil. Karaj *et al.* (2008)[27] carried out chemical analyses on Jatropha oil and compared the results with properties of rape oil and mineral oil EN 14214. They discovered that Jatropha oil competes favourably well with rape oil and mineral oil EN 14214 and concluded that it has a great role as a basestock for green fuel.

3.2. Neem (*Mellia azadirachta*) Oil

Neem seed is a part of the Neem tree which has high concentration of oil (about 25 – 45%). Orhevba and JohnPaul (2016) [28] reported density of 0.928 g/ml, viscosity at 40°C and 100°C of 39.30 cSt and 16.25 cSt respectively, viscosity index of 175, pour point of 5.2°C, flash point of 210°C, smoke point of 182°C, saponification value of 185.13 mgKOH/g, acid value of 7.40 mgNaOH/g, free fatty acid of 3.70%, peroxide value of 9.00 meq/kg and iodine value of 116.00 gI_2/100g for Neem oil. The Neem bio-lubricant produced by Orhevba and JohnPaul (2016)[28] using trans-esterification method was synthesized and the major lubricating properties of the synthesized bio lubricant were analyzed. The bio-lubricant when compared with standards as specified by ISO conform to those of viscosity grade 32 (VG-32) and hence concluded that the synthesized bio-lubricant can satisfactorily serve as substitute for petroleum based lubricants for industrial and agricultural machines.

Chebattina *et al.* (2018) [29] developed lubricant from Neem oil and found out that the production of bio-lubricant from Neem oil using various alcohols has potential to replace the petroleum based lubricants. They reported that the neem oil shows potential supply of bio-lubricants owing to the physicochemical properties which are comparable to petroleum based lubricants and they are environmentally friendly. Olufemi and Essien (2020) [30] produced bio-lubricant from Neem seed oil catalyzed by calcium oxide from snail shell. The bio-lubricant produced showed good agreement when compare to other plant based bio-lubricant and the International Standards Organisation Viscosity Grade 46 (ISO VG 46) commercial standards for light and industrial gear applications. They concluded that the synthesized neem bio-lubricant can preferably serve as a substitute for petroleum based lubricants in light and industrial gear applications. Chauhan (2015) [31] reported that Neem is the cheapest source of eco-friendly, bio-degradable and non-convention energy resources and can be used up to most of the moderate temperature operations such as metal working lubricants, 2 stroke engine oils, refrigeration oils, hydraulic oils, and as a base fluids for environmental friendly greases.

3.3. Karanja (*Pongamia pinnata*) Oil

Karanja is a genus of legume plant family, easily cultivable and can grow in semi-arid conditions. It is distributed in tropical and subtropical regions of the world. Karanja seeds are good source of oleic acid as its percentage is 51.59 and are thermally stable than poly unsaturated fats, and therefore are highly desired component in vegetable oils for lubricant applications according to Chauhan and Chhibber (2013) [32]. Karanja oil as reported by Agrawal *et al.* (2017) [9] has density of 0.936 g/ml, viscosity at 40°C and 100°C of 54.54 cSt and 15.18 cSt respectively, viscosity index of 304.9, pour point of -1°C, flash point of 220°C, fire point of 240°C, saponification value of 188.5 mgKOH/g and acid value of 18.40 mgKOH/g. They compared the physico-chemical properties of Karanja based bio-lubricant with 2T engine oil and discovered that the bio-lubricant compete favourably with the 2T engine oil. Panchal (2018) [33] reported researches that were carried out on chemically modified Karanja oil. The results according to their report show that the oil can be employed in the production of bio-lubricant. The Karanja-based lubricants obtained was comparable to petroleum-based product and can be used in the same applications where mineral-oils usually used. It was also reported that the percentage of unsaturation presence in the structure of the vegetable oil which can lead to oxidation was drastically reduced through epoxidation.

Sharma and Sachan (2019) [34] reported in their study that Karanja oil based bio-lubricant performed excellently in terms of friction and wear characteristics along with high thermal stability and energy efficiency. The study found that Karanja oil based bio-lubricant has lowest coefficient of friction and wear scar diameter than any vegetable oil, TMP ester or commercial lubricant. The energy efficiency and flash temperature parameter of the bio-lubricant were better compared to any vegetable oil, TMP ester and mineral lubricants. According to Sharma and Sachan (2019)[34], the bio-lubricant demonstrated the outstanding performance in terms of friction and wear characteristics along with high thermal stability and energy efficiency worthy of comparison with multiple lubricating products reported by different research groups in available literatures.

3.4. Mahua (*Madhuca indica*) Oil

Mahua oil is a non-edible vegetable oil obtained from the seeds of Mahua plant. Seeds from Mahua plants have an oil content of 35 – 40% and found to have the potential to be used as a bio-lubricant. Fatty acid composition of Mahua oil contains saturated components - 24% palmitic and 24% stearic acid, unsaturated components - 40% of oleic and 12% of linoleic acid according to Jain and Suhane (2014) [35]. Agrawal *et al.* (2017) [9] reported the physico-chemical properties of Mahua oil to include: density 0.907 gm/ml, viscosity at 40 °C and 100 °C 37.18 cSt and 11.66 cSt respectively, viscosity index 325.6, pour point 18°C, flash point 210°C, fire point 220°C, saponification value 185.13 mgKOH/g, and acid value 26.23 mgKOH/g. In their study, they compared the physico-chemical properties of the Mahua based bio-lubricant with 2T engine oil. The bio-lubricant compete favourably with the 2T engine oil and concluded that quality bio-lubricant can be successfully produced from Mahua oil.

A study made by Jain and Suhane (2014) [35] on the tribological characteristics of non-edible Castor and Mahua Oils as bio-lubricant for maintenance applications revealed that the blend of refined Castor oil with the refined Mahua oil have tremendous capacity to be used in gear applications. Coefficient of friction was found to be less than 0.02, on an average 90% reduction, thus higher reliability, better fuel economy and higher performance. There was average 45 to 63% wear reduction on metal parts, thus increase of mechanical operating efficiency and extension of application design life. They observed and reported that mahua oil based bio-lubricant has good wear reducing traits for maintenance purpose at different operating conditions.

3.5. Sandbox (*Hura crepitans*) Oil

Oniya *et al.* (2017) [36] described Sandbox tree (*Hura crepitans)* was described as an evergreen perennial and underutilized plant which is planted as a shade tree. It is recognized by the many dark and pointed spines, smooth brown dark and spreading branches. Sandbox seed has been reported to contain oil and the oil content was found to be 53.61% (w/w) (Okolie *et al.*, 2012) [37]. This relatively high oil content of the seed makes the *Hura crepitans* seed a good source of oil and making it economically viable. Sandbox oil is highly neglected non-edible oil available at little or no cost of purchase. Popoola and Ikpambese (2021) [38] reported that it has no specific use and no commercial value at present. Sandbox oil was described as a promising alternative lubricant basestock to mineral oil because it is environmentally friendly, renewable, cheap, and easily manageable (Popoola and Ikpambese, 2021) [38]. It contains high content of unsaturated fatty acid such as oleic acid.

Oleic acid has been proved as the most ideal monounsaturated fatty acid for bio-lubricant. This makes the oil suitable for bio-lubricant production because the presence of double bond will lower the melting point, which would enhance the low temperature performance of the bio-lubricants. Abdul-Fattah *et al.* (2017) [39] reported that fatty acid contained in some vegetable oils tends to cling to metal surfaces effectively and therefore provide improved lubricity.

Popoola and Ikpambese (2021) [38] analyzed the chemo-physical properties of Sandbox oil and bio-lubricant produced from nanoparticle-enriched Sandbox oil and reported that the crude Sandbox oil have density of 0.92±1 g/cm^3, specific gravity of 0.93 g/ml, refractive index of 1.4679, saponification value 245.98 mg KOH/g, iodine value of 177.66 gI$_2$/100g, acid value of 2.81 mg KOH/g, free fatty acid of 14.03 mg KOH/g, viscosity at 40°C and 100°C of 29.80 cSt and 7.90 cSt respectively, viscosity index of 172.96, pour point of -3°C, flash point 249°C and fire point 252°C, while the results of chemo-physical properties of the bio-lubricant conformed to the SAE standards. They concluded that Sandbox oil is a potential vegetable oil which can be used as alternative lubricant feedstock in automobile engine oil production because of its good chemo- physical properties besides the advantages of vegetable oil like renewability, biodegrability, and non-toxic.

4. Conclusion

There are great potentials in exploring non-edible vegetable oils as basestocks for bio-lubricants production. Various investigations had shown that non-edible vegetable oils are economical, have a high viscosity index, good wear performance, high flash point, low pour point, cloud point and they are environmentally friendly, renewable and biodegradable. These non-edible vegetable oils should be explored so as to conserve the edible oil for food and human consumption. More attention should be given to these oilseeds which if well harnessed can become cash crops for international markets now that the bio-based products are becoming popular. Large scale plantations of these seeds can provide energy security to the country, foreign exchange can be saved and hence it will provide employment to the rural masses. In addition, most mineral oil based lubricants should be replaced by bio-degradable bio-lubricants to prevent environmental pollution.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Abere, J.O. (2017). Improved performance of bio-lubricant by nanoparticles additives. Unpublished PhD Thesis, Department of Mechanical Engineering, University of Sheffield.

[2] Mehic, S.H. (2017). Additives in lubricant: Types and chemical composition of lubricant additives. Chemicals Office of the Republic of Slovenia.

[3] Jackson, R.P. (2012). Engineering tribology. PDH online. www.PDHonline.org.

[4] Khasbage, S., Patil, V. And Dhande, D. (2016). Performance of jatropha biolubricant for hydrodynamic journal bearing lubrication. International Research Journal of Engineering and Technology. 03(07): 627 – 632.

[5] Ilie, F. and Covaliu, C. (2016). Tribological properties of the lubricant containing titanium dioxide nanoparticles as an additive. Lubricants. 4(12): 1 – 13.

[6] Singh, K. and Suhane, A. (2016). Effect of additive addition in base oil of a lubricant – A review. International Research Journal of Engineering and Technology. 03(04): 2636 – 2639.

[7] Sayed, A., Ahmed, A.A. and Sherif, E. (2018). Review on investigation of tribological performance of a lubricant using nano additives. Int. Jour. of Adv. Sci. Res. and Mgmt (IJASRM). 3(7):103 – 118.

[8] Syahrullail, S., Wira, J.Y., Wan Nik, W.B. and Fawwaz, W.N. (2013). Friction characteristics of RBD palm olein using four-ball tribotester. Applied Mechanics and Materials. 315: 936 – 940.

[9] Agrawal, A.J., Karadbhajne, V.Y., Agrawal, P.S., Arekar, P.S. and Chakole, N.P. (2017). Synthesis of biolubricants from non edible oils. International Research Journal of Engineering and Technology. 04(07): 1753 – 1757.

[10] Ahmed, D.I., Kasolang, S., Dwyer-Joyce, R.S., Sainan, K.I. and Nik Roselina, N.R. (2014). Formulation and physico-chemical characteristics of biolubricant. Jurnal Tribologi. 3: 1 – 10.

[11] Syaima, M.T.S, Zamratul, M.I.M., Noor, I.M. and Rifdi, W.M.W.T. (2014). Development of biolubricant from Jatropha curcas oils. Int'l Journal of Research in Chemical, Metallurgical and Civil Engg. (IJRCMCE). 1(1): 10 – 11.

[12] Srivastava, A. and Sahai, P. (2013). Vegetable oils as lube basestocks: A review. African Journal of Biotechnology. 12(9): 880 – 891.

[13] Jabal, M.H., Ani, F.N. and Syahrullail, S. (2014). The tribological characteristic of the blends of RBD palm olein with mineral oil using four-ball tribotester. Jurnal Tecknologi. 69(6): 11 – 14.

[14] Gulzar, M. (2017). Tribological study of nanoparticles enriched bio-based lubricants for engine piston ring – cylinder interaction. Unpublished PhD Thesis, Faculty of Engineering, University of Malaya, Kuala Lumpur.

[15] 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 and non-edible feedstock. 22: 346 – 360.

[16] Garces, R., Martinez-Force, E. and Salas, J.J. (2011). Vegetable oil basestocks for lubricants. Grasas Y Aceites. 62(1): 21 – 28.

[17] Singh, Y. (2015). Tribological behaviour as lubricant additive and physiochemical characterization of Jatropha oil blends. Friction. 3(4): 320 – 332.

[18] Khandelwa, S. and Chauhan, Y.R. (2012). Biodiesel production from non-edible oils: A Review. Journal of Chemical and Pharmaceutical Research. 4(9): 4219 – 4230.

[19] Kalam, M.A., Masjuki, H.H., Shahabuddin, M. and Mofijur, M. (2012). Tribological characteristics of amine phosphate and octylated/butylated diphenylamine additives infused bio-lubricant. Energy Education Science and Technology. 30(1):123 – 136.

[20] Owuna, F.J., Dabai, M.U., Sokoto, M.A., Dangoggo, S.M., Bagudo, B.U., Birnin-Yauri, U.A., Hassan, L.G., Sada, I., Abubakar, A.L. and Jibrin, M.S. (2020). Chemical modification of vegetable oils for the production of biolubricants using trimethylolpropane: A review. Egyptian Journal of Petroleum. 29(2020):75-82.

[21] Izah, S.C. and Ohimain, E.I. (2013). The challenge of biodiesel production from oil palm feedstock in Nigeria. Greener Journal of Biological Sciences. 3(1): 001 – 012.

[22] Bilal, S., Mohammed-Dabo, I.A., Nuhu, M., Kasim, S.A., Almustapha, I.H. and Yamusa, Y.A. (2013). Production of biolubricant from Jatropha curcas seed oil. Journal of Chemical Engineering and Materials Science. 4(6): 72 – 79.

[23] Habibullah, M., Masjuki,H.H., Kalam, M.A., Asraful, M.A., Habib, M.A. and Mobarak, H.M. (2014). Effect of bio-lubricant on tribological characteristics of steel. Procedia Engineering. 90: 740 – 745.

[24] Mohammed, H.J, Muhannad, Z.K. and Abdulmunem, R.A. (2018). Tribological performance of mustard seeds oil under different loads using pin-on-disk tribotester. The Iraqi Journal For Mechanical and Material Engineering. 18(4): 527 – 537.

[25] Golshokouh, I., Saimon, S., Ani, F.N., and Golshokouh, M. (2013). Jatropha oil as alternative source of lubricant oil. Life Science Journal. 10(8s):268-276.

[26] Menkiti, M.C., Ocheje, O. and Agu, C.M. (2017). Production of environmentally adapted lubricant basestock from Jatropha curcas specie seed oil. Int. J. Ind. Chem. 8: 133 – 144.

[27] Karaj, S. Huaitalla, R. M. and Miller, J. (2008). Physical, mechanical and chemical properties of Jatropha curcas L. seeds and kernels. Conference on International Agricultural Research for Development. October 07-09.

[28] Orhevba, B.A. and JohnPaul, A.F. (2016). Synthesis of bio-lubricant from neem seed (Azadirachta indica) oil for agricultural machines. Repository. Federal University of Technology, Minna, Nigeria. 1 – 12.

[29] Chebattina, K.R.R., Chaitanya, C.U and Padmaja, D.V. (2018). Synthesis of Neem oil esters as bio-lubricant base stock. International Journal of Management, Technology and Engineering. 8(XII):3659 – 3665.

[30] Olufemi, B.A. and Essien, R.A. (2020). Production of biolubricants from neem seed oil catalyzed by calcium oxide from snail shell. Acta Technica Corviniensis – Bulletin of Engineering. XIII(3): 107 – 113.

[31] Chauhan, P.S. (2015). Study of Neem oil as a source of Biolubricant. VIVECHAN International Journal of Research. 6(1): 62 – 69.

[32] Chauhan, P.S and Chhibber, V.K. (2013). Chemical modification in Karanja oil for bio-lubricant industrial applications. Journal of Drug Delivery and Therapeutics. 3(3):117 – 122.

[33] Panchal, T., Patel, A., Thomas, M. and Patel, J. (2018). Development of lubricants from renewable resource: an approach towards value added product from vegetable oil. Paper presented at the 24th European Biomass and Conference Exhibition.

[34] Sharma, U.C. and Sachan, S. (2019). Friction and wear behavior of Karanja oil derived bio-lubricant base oil. SN Applied Sciences. 1:668 – 679.

[35] Jain, A.K. and Suhane, A. (2014). Investigation of Tribological Characteristics of Non Edible Castor and Mahua ils as Bio Lubricant for Maintenance Applications. 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th –14th, 2014, IIT Guwahati, Assam, India

[36] Oniya, O.O., Oyelade, J.O., Ogunkunle, O. and Idowu, D.O. (2017). Optimization of solvent extraction of oil from sandbox kernels (Hura crepitans L.) by a response surface method. Energy and Policy. 4(1): 36 – 43.

[37] Okolie, P.N., Uaboi-Egbemi, P.O. and Ajekwene, A.E. (2012). Extraction and quality evaluation of sandbox tree seed (Hura crepitan) oil. World Journal of Agricultural Sciences. 8(4): 359 – 365.

[38] Popoola, C.A. and Ikpambese, K.K. (2021). Effect of Titanium Oxide Nanoparticle Enrichment on Chemo-Physical Properties of Bio-Lubricant from Sandbox Seed Oil. Iconic Research and Engineering Journals. 4(10): 175 – 191.

[39] Abdul-Fattah, F.N. Ariff, M.A., Mohammed, H.J. and Farid, N.A. (2017). The tribological characteristics of rubber seed oil with mineral oil blends. *Malaysian Journal of Industrial Technology.* 2(2): 17 – 22.