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# The Role of *Eusideroxylon zwageri* Seed Oil Addition on Changing Triglyceride Geometry and Physical Properties of Crude Palm Oil

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## Abstract

*This study investigates the role of bioadditive Eusideroxylon zwageri seed oil in influencing the physical properties of crude palm oil. Simulated using HyperChem software, the molecular dynamics model reveals an alteration in the triglyceride geometry of vegetable oil resulting from the addition of a bioadditive. Procyanidin found in E. zwageri seed oil energized electrons on its aromatic ring cluster, generating a magnetic moment such that spinning electrons along the molecular chains of crude palm oil became more reactive. This enhanced electron mobility also correlated to lower dipole moment and higher kinetic energy, weakening the intermolecular Van der Waals' force between triglyceride molecules. As a result of this phenomenon, molecular geometric stretching along the carbon chain of triglycerides occurs, increasing the probability of altering the physical properties of the treated vegetable oil. The study result shows a modest reduction in kinematic viscosity (cSt) of the treated crude palm oil, as verified by the ASTM D 445 method, after the addition of the bioadditive seed oil. Flash point value also decreases marginally, as measured by the ASTM D93 method. The E. zwageri seed oil demonstrated an alternative bioadditive, enhancing the physical properties of vegetable oil fuel.*

***Index-words:*** *Eusideroxylon zwageri, Triglyceride geometry, Physical properties, Crude palm oil.*

## I. Introduction

Biodiesel sourced from vegetable oils has shown promise for participation in the global production of renewable energy [1]. Vegetable oils comprise triglyceride chains, oxygen-abundant molecules with three fatty acid tails attached to a single glycerol head, connected by ester bonds, which can be either solid or liquid at room temperature [2]. The fatty acid tails are made up of long-chain carbon atoms, combined with hydrogen, and a carboxyl group [3]. Because vegetable oil fuels acquire similar properties to petrol fuels, the direct utilisation of the oils in diesel engines has been possible with slight engine modifications and/or some operating precautions [4]. However, the main drawbacks of vegetable oil fuels stem from their high viscosity, along with the low evaporation and reactivity of unsaturated hydrocarbon carbon chains [5]. Highly viscous fuels compromise the atomization process, leading to incomplete combustion and various component-related problems, such as engine deposit build-up, injector clogging, and pumping wear [6].

Researchers have investigated numerous ways to manipulate the high-viscosity problem of vegetable oil, for instance, by preheating [7,8], blending [9], and using microemulsion methods [10]. The blending method has been regarded as an efficient and cost-effective approach. Alcohol components, such as butanol and pentanol, showed up as recommended additive agents to mitigate the high-viscosity effect of vegetable oil [9-11]. Other agents, such as synthetic manganese (Mn), have also been reported to improve the viscosity and flash point of biofuel derived from pomace oil [12]. All these studies concluded that these chemical-based additive materials resulted in improved viscosity and/or flash point level compared to the original ones. Yet, none of these studies explored the scientific explanation at the molecular level. Therefore, more studies are required to gain a deeper understanding of the basic explanation at the molecular level.

Studies on plant-based products as additives, aiming to enhance the properties of vegetable oil fuels, have been conducted. Higher blending proportions of turpentine oil resulted in improved viscosity and calorific value [13]. Eucalyptus oil and Bamboo carbon nanoparticles have been reported to enhance the viscosity and combustion reactivity of the treated vegetable oils [14, 15]. In their studies, researchers suggested that the nature of the fatty acid composition, the difference in electronegativity between the additive and the vegetable oils, the presence of aromatic ring clusters, and other features are responsible for potential alterations in the physical and chemical properties of the treated oils [14-16]. Hence, we are motivated to explore novel plant-based materials with comparable characteristics, aiming to prospectively improve eco-friendly vegetable oil fuels.

The concept of aromaticity at the molecular level and its relevance in triggering a magnetic moment is an interesting phenomenon. Barlini and colleagues described the theoretical and experimental justification for how a magnetic moment is generated within a molecular aromatic ring via NMR (Nuclear Magnetic Resonance) [17]. A Computational study also demonstrated the relevance of how aromatic ring systems could produce a magnetic moment, which modifies their surrounding molecules [18]. These aromatic ring clusters acquire delocalized electrons, triggering a degree of magnetic field [19-21], which in turn induces stronger electron spins in the surrounding molecules, such as water and lipid molecules, leading to enhanced physical and chemical properties of the treated oils [14-16]. Therefore, the idea of bridging the aromatic system's potential magnetic effects with lipid alignment phenomena and applying it in the area of vegetable oil fuel has become the focus of this study.

The focus of the present study is to assess the role of natural additive *Eusideroxylon zwageri* seed oil towards the viscosity and flash point of crude palm oil. Characterization tests, along with the HyperChem molecular dynamics simulation model to note the molecular geometric changes, were performed to gain insight into the underlying mechanism of action at the molecular level. The constituent elements within *E. zwageri* seed oil may attach to the triglyceride chains of the CPO due to differences in electronegativity, triggering attractive-repulsive forces that activate the mobility of atoms. This change in the mobility of atoms could impact the overall triglyceride geometric structure of the treated oil, potentially altering its properties.

The *Eusideroxylon zwageri* plant is chosen because this tree is endemic and native to Sumatra and Borneo, Indonesia. Its seeds contain flavonoids, a class of polyphenolic metabolites, which are suggested to act as antioxidants and anti-inflammatory agents [22]. Polyphenol substances feature aromatic ring clusters along with hydroxyl groups [23]. These features may have the potential to influence the physical and chemical characteristics of vegetable oil. Crude Palm Oil (CPO) is used in this study due to its wide availability in Indonesia, which makes it a prime raw material for alternative biofuels. Additionally, due to its simple processing practices and positive economic outlook, CPO has been anticipated as a substitute fuel for low- to medium-speed diesel power plants across Indonesia [24].

## II. Experimental

### A. Material collection and preparation

*Eusideroxylon zwageri* fruit was gathered from a plantation in Samboja, East Borneo. The seed was collected from mature fruit, chopped into chips, and then dried under adequate sunlight for two days to reduce moisture content. The seed oil was extracted by cold-pressing the *E. zwagery* seed using a pressing apparatus (MKS-J01, Indonesia). The step-by-step preparation process is presented in Figure 1. This cold-press method for oil extraction is regarded as a sustainable technique, as it generates no chemical effluent while still preserving the components of the extracted seed oil [25].

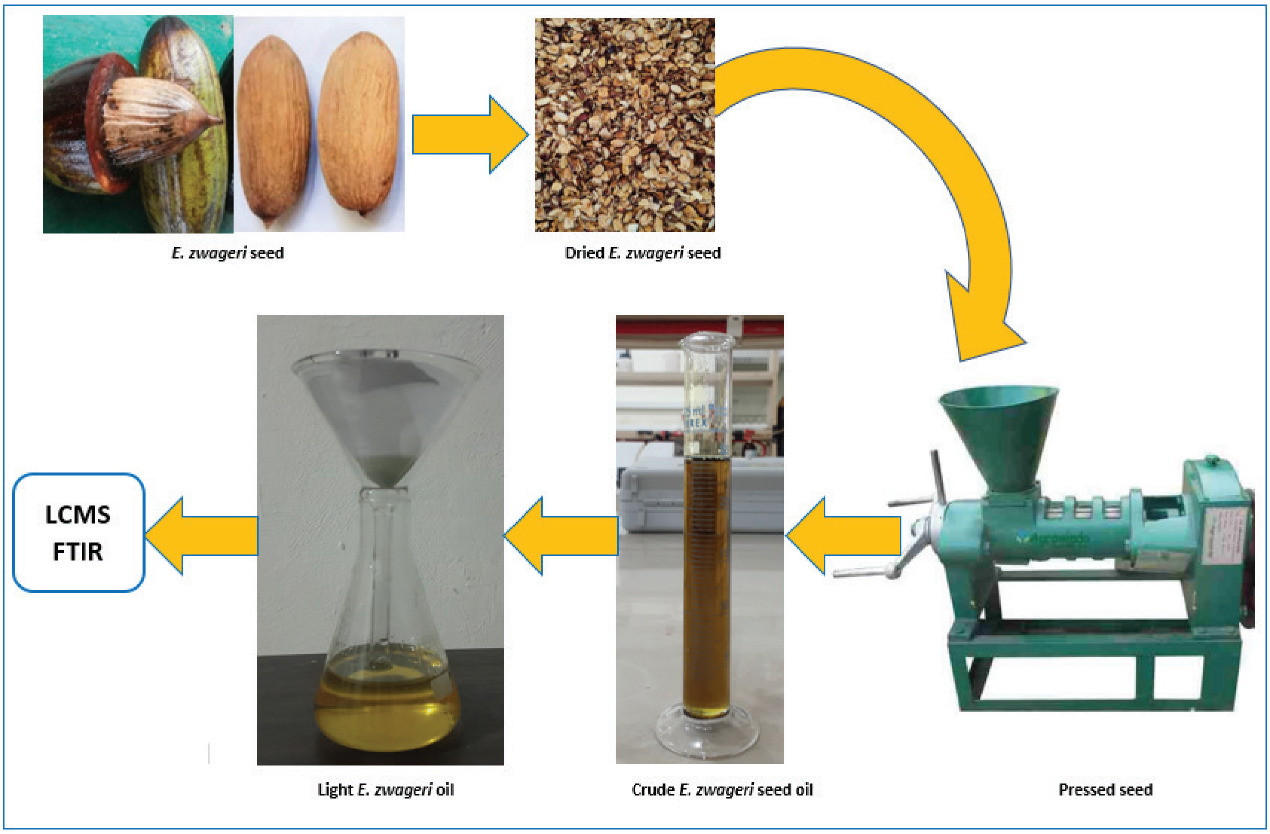


Figure 1: Preparation process of *E. zwageri* seed oil before characterization.

Crude palm oil was sourced from local oilseed cultivars in Balikpapan, East Borneo. The fatty acid composition of CPO is presented in Table 1.

Table 1: Fatty acid composition of CPO [26]

| Chemical composition | Cn; db | Composition (%) | Molecular mass, g/mole |
|---|---|---|---|
| Caprylic acid | 8;0 | 0.08 | 144.2114 |
| Capric acid | 10;0 | 0.06 | 172.2646 |
| Lauric acid | 12;0 | 0.36 | 200.3178 |
| Myristic acid | 14;0 | 1.13 | 228.3709 |
| Palmitic acid | 16;0 | 42.31 | 256.4241 |
| Palmitoleic acid | 16;1 | 0.17 | 254.4882 |
| Stearic acid | 18;0 | 4.27 | 284.4772 |
| Oleic acid | 18;1 | 40.90 | 282.4614 |
| Linoleic acid | 18;2 | 10.07 | 280.4455 |
| Linolenic acid | 18;3 | 0.28 | 278.4296 |
| Arachidic acid | 20;0 | 0.31 | 312.5304 |
| Gondoic acid | 20;1 | 0.16 | 310.5145 |

*Cn (the number of carbon atoms); db (the number of double bonds)*

## B. *Seed oil characterizations*

### 1. LC-MS/MS-QtoF analysis

After the preparation process, the extracted seed oil was applied for compound identification according to the modified method by [27]. An amount of 4 μL of treated *Eusideroxylon zwageri* seed oil was injected into the LC-MS/MS-QtoF (Waters Xevo G2-S, USA) system, which incorporated both positive and negative Electrospray Ionization. This component identification test uses the LC-MS/MS-QtoF system, integrated with a mass spectra library and the UNIFY information system.

### 2. FTIR analysis

FTIR (Bruker ALPHA II, Germany) is used to identify functional groups in prepared *Eusideroxylon zwageri* seed oil by measuring the wavelength spectra in the infrared region absorbed by the seed oil sample. In this study, the focus is on determining the aromatic ring cluster in the seed oil [28].

## C. *Molecular dynamics simulation model*

Molecular dynamics simulation, using HyperChem software, was performed to illustrate the interaction between the bioadditive *Eusideroxylon zwageri* seed

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oil and crude palm oil. Computation on electron mobility, molecular kinetic energy, and dipole moment was also presented. To simplify, the simulation involved one molecule of procyanidin, a prominent constituent of *E. zwageri* seed oil, and one triglyceride molecule of crude palm oil, as shown in Figure 2. The simulation temperature started at 120 K, with a step temperature of 60 K, and a final simulation temperature of 360 K.

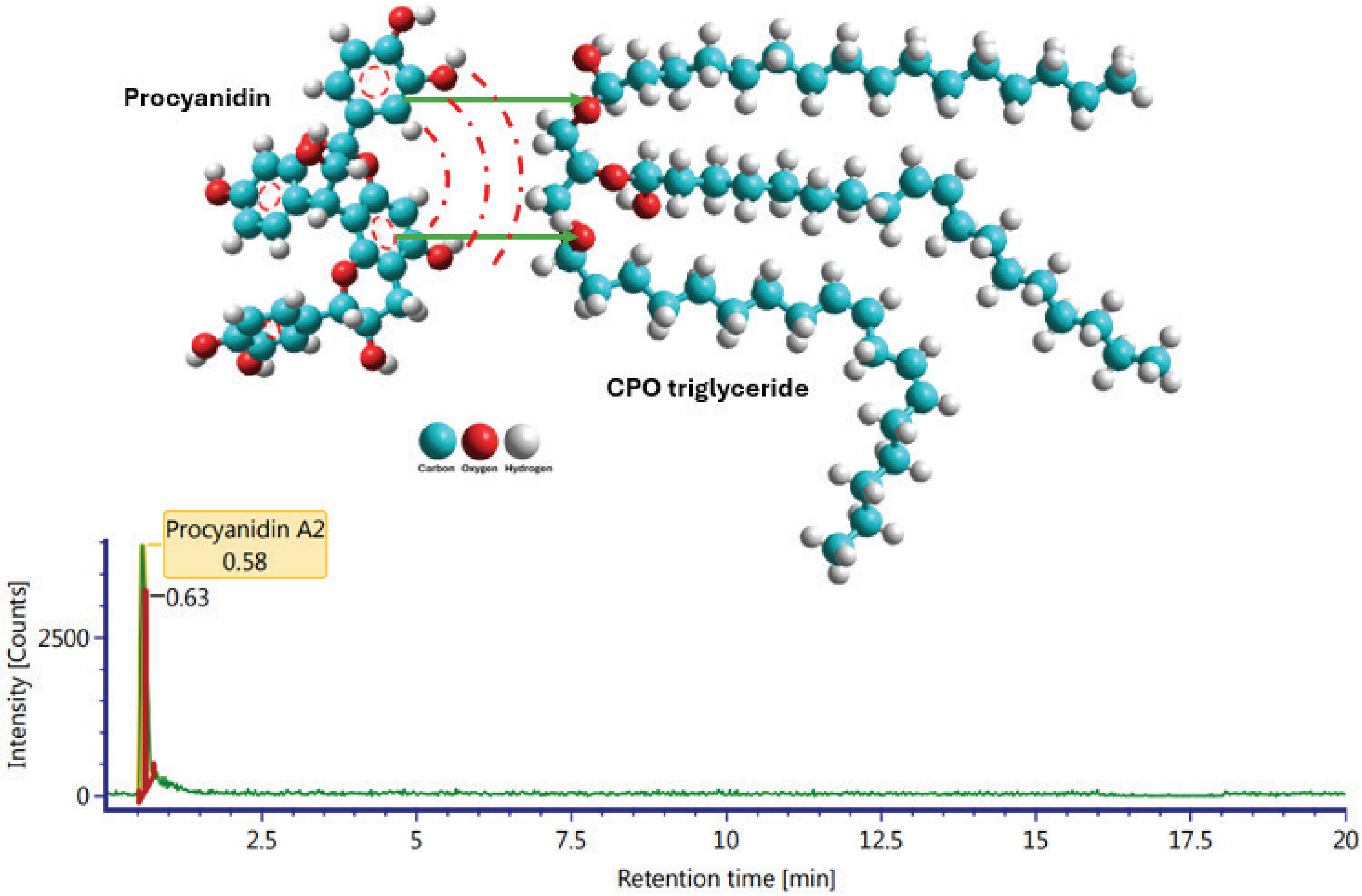


Figure 2: Molecular model for procyanidin and CPO triglyceride.

### D. Viscosity and flash point measurements

*Eusideroxylon zwageri* seed oil at a dose of 5% v/v was added to 400 mL of crude palm oil, which was then conditioned at 40 °C and stirred using a magnetic stirrer for 30 minutes. Then, the mixture was allowed to settle for approximately 12 hours at room temperature. The kinematic viscosity of a stable mixture of crude palm oil, combined with the concentration of *E. zwageri* seed oil, was measured using an Ostwald viscometer according to the ASTM D445 standard [29]. Meanwhile, the flash point test was conducted using a standardized flash point measurement tool, SYD-261, by the closed cup method, following the ASTM D93 standard [30]. For the viscosity and flash point measurements, all sample data were measured in triplicate, and then the mean values and their standard deviation were reported.

## III. Results and Discussion

### A. Material characterizations

The LC-MS test indicated that the prepared *Eusideroxylon zwageri* seed oil contained procyanidin, several flavonoid-derivative substances, and cnidimol at low response. This LC-MS result is comparable to a previous qualitative study on the seed oil [22]. Amongst these components of the seed oil, procyanidin can interact with vegetable oil as shown in Figure 2. Due to the difference in electronegativity, the positively charged procyanidin can readily interact with the negatively charged carbonyl group along the crude palm oil triglycerides [31].

Procyanidin is a polyphenolic compound derived from the condensation of epicatechin, which has two ring hydroxyl groups and exhibits antioxidative properties [32]. Thus, as polyphenol oligomers, aromatic rings clustered with hydroxyl groups are readily present in the prepared *Eusideroxylon zwageri* seed oil. These aromatic rings' characteristics include delocalized electrons that generate a degree of magnetic field, boosting the spinning electrons along the molecular chain of vegetable oil [19-21]. This increased level of electron spinning/mobility contributed to an increased molecular kinetic energy [33], weakening the intermolecular Van der Waals' force of the triglyceride chains and stretching apart the molecular structure of the treated crude palm oil, as illustrated in the Figure. 4. This stretching distance along the carbon chains of the CPO reduced the thickness of the treated oil. Moreover, the decrease in carbon atom bonding also facilitated better combustion reactivity as indicated by a lowered flash point level.

FTIR test result of *Eusideroxylon zwageri* seed oil, as shown in Figure 3, indicated a peak in the spectrum of 1400-1600, corresponding to the C=C aromatic rings, followed by an absorbance band of 3000-3100. There are also several peaks in the spectra of 1000-1300 supporting evidence for aromatic ring band (C-H in-plane functional group) [34]. Additionally, a single absorbance band was observed in the region between 670 and 850 nm, which corresponds to an aromatic ring band [28]. Delocalized electrons in aromatic ring clusters have the potential to induce a magnetic field [19, 20]. Additionally, intermediate and large aromatic compounds acquired delocalized electrons, retaining ring currents that generated a magnetic field [21, 22]. The resultant magnetic moment, in turn, impacted the surrounding molecular structure. [14-16]. Therefore, as suggested by [19-22] and supported by the FTIR test, bioadditive *E. zwageri* seed oil could induce a magnetic moment, which influences the molecular geometry of the crude palm oil triglyceride chains, leading to reduced viscosity and flash point levels. (Further discussed in section 3.2).

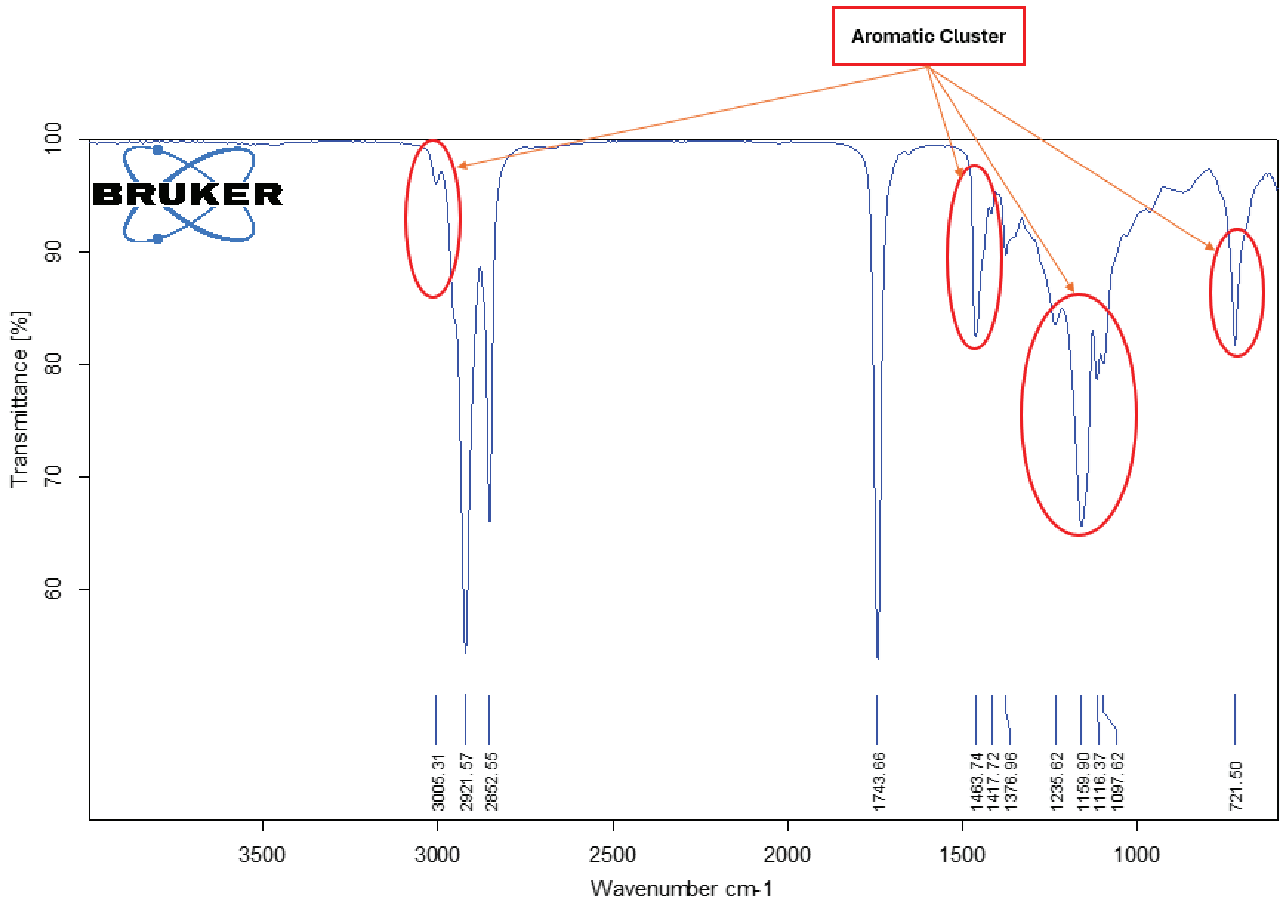


Figure 3: FTIR test result.

### *B. Molecular geometry alteration*

The nature of vegetable oils, such as the length of the fatty acid chains, their composition, and the level of saturation, influences their chemical and physical properties [26]. The largest fatty acid components of crude palm oil are palmitic, oleic, and linoleic, as shown in Table 1. These components contained more than 50% double bonds and approximately 10% polyunsaturated fatty acids. These features provide a relatively rigid and curly form of the molecular geometry of CPO triglyceride chains, as simulated by HyperChem software.

As bioadditive *Eusideroxylon zwageri* seed oil interacts with the triglyceride chains of the crude palm oil, molecular geometric alteration occurs. When the prepared seed oil was added to the CPO, the weak attraction-repulsion intermolecular force, namely, the Van der Waals force, which sustained fatty acid chains of the oil in a liquid state, was disrupted. This happened due to the local magnetic induction triggered by delocalized electrons energizing electrons' mobility, which acted along the side of the triglyceride molecule. Consequently, the initial curly-rigid shape of the CPO carbon chains stretched slightly, suggesting that the presence of bioadditive *E. zwageri* seed oil exerted molecular geometric relaxation along the carbon chains of the vegetable oil. This bioadditive stretching effect was observed in all three fatty acid chains of the Hyperchem simulation model, as shown in Figure 4. However, the least tearing apart was noted on the last chain of the triglyceride molecule, which corresponded to linoleic acid. More double bonds are present in linoleic acid, making the impact of triggered magnetic induction by the procyanidin molecule the least on this last chain. This finding followed the fact that the presence of double bonds could hamper the electron mobility's additive effect [35].

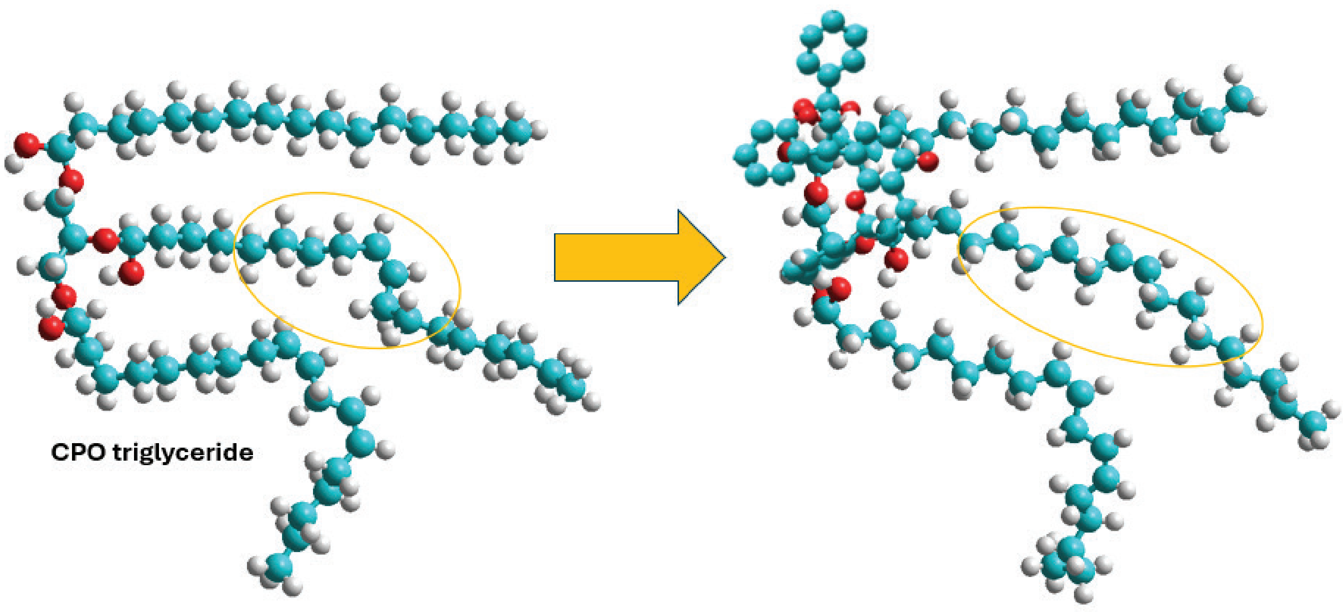


Figure 4: Molecular geometry of the CPO triglyceride chains before and after adding *E. zwageri* seed oil.

In addition, the interaction between the triglyceride chains of vegetable oil and the bioadditive enforced certain molecular dynamic energy, which is represented by kinetic energy [33]. Simulated at 360K, the kinetic energy developed from this CPO + bioadditive interaction was 1186.52 kcal/mol, while that of CPO per se was 782.33 kcal/mol. This elevated CPO+ bioadditive kinetic energy correlated to higher electron mobility that emerged along the carbon chains of the treated vegetable oil. An increased electron activity level also increased the probability of their collisions, triggering disruption in the intermolecular Van der Waals force along the vegetable oil [36].

From a quantum chemistry perspective, the electron polarization of a molecule fluctuates in response to changes in its energy state. Electron polarization, indicated by the dipole moment, correlates with intermolecular binding energy, suggesting that a stronger dipole moment represents a stronger intermolecular interaction, thereby inhibiting electron mobility [37]. HyperChem simulation showed a decrease in dipole moment, μ (debyes), of the treated vegetable oil after the addition of the *E. zwageri* seed oil. ($\mu_0$ =8.526 to $\mu_1$ = 2.173). Bioadditive seed oil, having delocalized electrons, generated a magnetic moment, energized the electron mobility along the triglyceride molecule, resulting in a more

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chaotic atomic movement, and a decline in dipole moment. This decrease in dipole moment, or increase in electron mobility, corresponds to an increase in the kinetic energy of the treated vegetable oil.

The phenomenon of molecular geometric stretching along the triglyceride chains of the vegetable oil (the changes in triglyceride packing or conformation as simulated by HyperChem), the diminishing Van der Waals bonding force, a decrease in dipole moment, and the increased kinetic energy due to the addition of bioadditive *E. zwageri* seed oil simultaneously result in viscosity decline of the treated crude palm oil. Likewise, the diminishing Van der Waals force along the triglyceride chains of the vegetable oil leads to better combustion reactivity, as indicated by a lower flash point.

Computational molecular modelling, such as HyperChem, can provide a valid methodology supporting scientific phenomena. In the broader context of sustainable energy-related fields, studies have incorporated various computational intelligence methods, which are conceptually in line with the use of HyperChem in this study. Moyo and Dewa, in their review, highlighted the use of computational modelling for sustainable energy systems [38]. Felobes and Abadir employed a molecular modelling approach to demonstrate the transformation process of biomass-derived oil [39]. Moreover, Makadia and Dave provided methodological support for computational modelling of energy-related substances, which is similar in spirit to this study's HyperChem simulation of oil properties [40].

### C. *Viscosity and flash point assessment*

There is a modest improvement in viscosity and flash point resulting from adding bioadditive *Eusideroxylon zwageri* seed oil to the prepared crude palm oil, as shown in Figure 5.

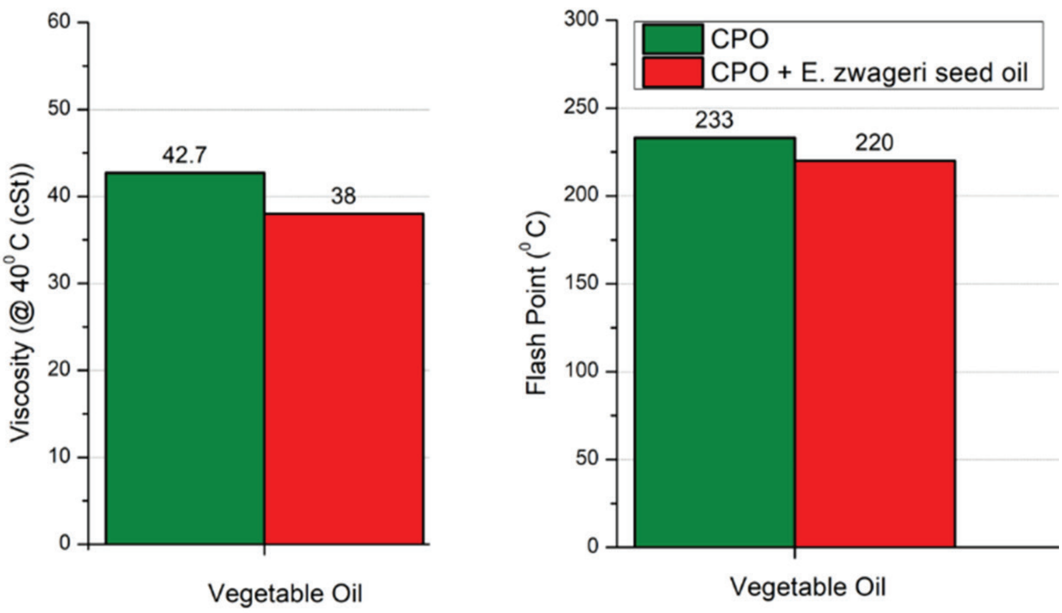


Figure 5: The viscosity and flash point of crude palm oil (CPO) with/without bioadditive *E. zwageri* seed oil.

A reduction in viscosity level occurred due to the weakening of the intermolecular Van der Waals forces in the triglyceride chains of CPO. Intermolecular force is a crucial variable in determining the viscosity level [41]. Aromatic ring clusters found in *E. zwageri* seed oil generate a magnetic field, which strengthens electron spinning and mobility along the fatty acid chains, thereby lowering the dipole moment, disrupting Van der Waals interactions among atoms, and altering the lipid conformation by stretching or extending the molecule. Therefore, the viscosity level of the treated crude palm oil declined by 11% (from 42.7 to 38 cSt). Flash point level also marginally improved by 6% because a decrease in the intermolecular Van der Waals force correlated to less energy to evaporate the oil [42]. Flash point refers to the minimum temperature at which a liquid produces sufficient steam to start combustion. Hence, a lower flash point corresponds to enhanced combustion reactivity, making the liquid more easily combustible.

According to the Indonesian National Standard SNI 8384, for CPO used as fuel in a low-speed diesel engine that also incorporates a thermal boiler in its operation, the viscosity level must be below 40, while the flashpoint level must be a minimum of 200 °C [43]. By this benchmark, our study results satisfactorily met the requirements.

The limitation of using one molecule of procyanidin per se in interaction with crude palm oil should be noted in this study. The presence of other components in the seed oil (considering the seasonal variation of the seed oil), although in minimal amounts, may have influenced the overall properties of the treated crude palm oil to some degree. Composition should have affected the thermophysical system performance [44]. Nevertheless, at the lab scale, our experimental results showed improvement in two parameters (kinematic viscosity and flash point) of CPO physical properties.

## IV. Conclusion

The addition of *Eusideroxylon zwageri* seed oil into the crude palm oil resulted in a modest decline in viscosity and flash point of the vegetable oil. Procyanidin found within the treated *E. zwageri* seed oil acquired delocalized electrons on its aromatic rings. These delocalized electrons emerged with a magnetic moment, which boosted the electron spin among the fatty acid chains of the CPO, decreased the dipole moment, and disrupted the intermolecular Van der Waals forces of the triglyceride chains of the CPO, such that its molecular geometry became more relaxed and/or stretched, as simulated by HyperChem software. This diminishing intermolecular Van der Waals force along the CPO molecule was marked by a reduction in the thickness of the treated crude palm oil (kinematic viscosity declined by 11%). Furthermore, lower energy is required to evaporate from this reduced Van der Waals bonding along the triglyceride chains of the crude palm oil, facilitating a better flash point level (an improvement of 6%).

This study suggested that an additive derived from a natural product, prepared in a simple and environmentally friendly procedure, could provide an alternative as an improver of biofuels' properties. For practical implications at a larger scale, a study on engine compatibility for long-term use should be done. In addition, further studies on LCA (Life Cycle Assessment) and techno-economic feasibility should not be overlooked, so that the extracted seed oil can be used as a bioadditive, especially for CPO fuels in low- to medium-speed engines with boilers in their operations.

## References

[1] A. E. Atabani *et al.*, "Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production," *Renewable and Sustainable Energy Reviews*, vol. 18, pp. 211–245, Feb. 2013, doi: 10.1016/j.rser.2012.10.013.

[2] S. A. Çelik and Y. Kan, "Determination of Fatty Acid Profiles and Antioxidant Activities of Some Edible Oils Consumed in Turkey," *Selcuk Journal of Agricultural and Food Sciences*, Aug. 2024, doi: 10.15316/SJAFS.2024.031.

[3] G. Toscano, G. Riva, E. Foppa Pedretti, and D. Duca, "Vegetable oil and fat viscosity forecast models based on iodine number and saponification number," *Biomass Bioenergy*, vol. 46, pp. 511–516, Nov. 2012, doi: 10.1016/j.biombioe.2012.07.009.

[4] J. Blin *et al.*, "Characteristics of vegetable oils for use as fuel in stationary diesel engines—Towards specifications for a standard in West Africa," *Renewable and Sustainable Energy Reviews*, vol. 22, pp. 580–597, Jun. 2013, doi: 10.1016/j.rser.2013.02.018.

[5] R. D. Misra and M. S. Murthy, "Blending of additives with biodiesels to improve the cold flow properties, combustion and emission performance in a compression ignition engine—A review," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 5, pp. 2413–2422, Jun. 2011, doi: 10.1016/j.rser.2011.02.023.

[6] N. Yilmaz and F. M. Vigil, "Potential use of a blend of diesel, biodiesel, alcohols and vegetable oil in compression ignition engines," *Fuel*, vol. 124, pp. 168–172, May 2014, doi: 10.1016/j.fuel.2014.01.075.

[7] S. Bari, T. H. Lim, and C. W. Yu, "Effects of preheating of crude palm oil (CPO) on injection system, performance and emission of a diesel engine," *Renew Energy*, vol. 27, no. 3, pp. 339–351, Nov. 2002, doi: 10.1016/S0960-1481(02)00010-1.

[8] O. M. I. Nwafor, "Emission characteristics of diesel engine running on vegetable oil with elevated fuel inlet temperature," *Biomass Bioenergy*, vol. 27, no. 5, pp. 507–511, Nov. 2004, doi: 10.1016/j.biombioe.2004.02.004.

[9] A. Atmanli, E. Ileri, B. Yuksel, and N. Yilmaz, "Extensive analyses of diesel–vegetable oil–n -butanol ternary blends in a diesel engine," *Appl Energy*, vol. 145, pp. 155–162, May 2015, doi: 10.1016/j.apenergy.2015.01.071.

[10] D. H. Qi, C. Bae, Y. M. Feng, C. C. Jia, and Y. Z. Bian, "Combustion and emission characteristics of a direct injection compression ignition engine using rapeseed oil based micro-emulsions," *Fuel*, vol. 107, pp. 570–577, May 2013, doi: 10.1016/j.fuel.2013.01.046.

[11] T. Laza and Á. Bereczky, "Basic fuel properties of rapeseed oil-higher alcohols blends," *Fuel*, vol. 90, no. 2, pp. 803–810, Feb. 2011, doi: 10.1016/j.fuel.2010.09.015.

[12] S. Çaynak, M. Gürü, A. Biçer, A. Keskin, and Y. İçingür, "Biodiesel production from pomace oil and improvement of its properties with synthetic manganese additive," *Fuel*, vol. 88, no. 3, pp. 534–538, Mar. 2009, doi: 10.1016/j.fuel.2008.09.031.

[13] P. Dubey and R. Gupta, "Influences of dual bio-fuel (Jatropha biodiesel and turpentine oil) on single cylinder variable compression ratio diesel engine," *Renew Energy*, vol. 115, pp. 1294–1302, Jan. 2018, doi: 10.1016/j.renene.2017.09.055.

[14] E. Marlina, W. Wijayanti, L. Yuliati, and I. Wardana, "The role of 1.8-cineole addition on the change in triglyceride geometry and combustion characteristics of vegetable oils droplets," *Fuel*, vol. 314, p. 122721, Apr. 2022, doi: 10.1016/j.fuel.2021.122721.

[15] S. Syahruddin, L. Yuliati, D. Widhiyanuriyawan, and I. N. G. Wardana, "The role of activated carbon nanoparticles on hydro-degumming non-edible vegetable oils," *Alexandria Engineering Journal*, vol. 61, no. 6, pp. 4729–4739, Jun. 2022, doi: 10.1016/j.aej.2021.10.025.

[16] D. Perdana, L. Yuliati, N. Hamidi, and I. N. G. Wardana, "The Role of Magnetic Field Orientation in Vegetable Oil Premixed Combustion," *Journal of Combustion*, vol. 2020, pp. 1–11, Jan. 2020, doi: 10.1155/2020/2145353.

[17] A. Barlini, A. Bianchi, E. Ronca, and H. Koch, "Theory of Magnetic Properties in Quantum Electrodynamics Environments: Application to Molecular Aromaticity," *J Chem Theory Comput*, Sep. 2024, doi: 10.1021/acs.jctc.4c00195.

[18] S. Shil, D. Bhattacharya, A. Misra, and L. Bytautas, "Antiaromatic Molecules as Magnetic Couplers: A Computational Quest," *J Phys Chem A*, vol. 128, no. 5, pp. 815–828, Feb. 2024, doi: 10.1021/acs.jpca.3c05784.

[19] D. Ajami, O. Oeckler, A. Simon, and R. Herges, "Synthesis of a Möbius aromatic hydrocarbon," *Nature*, vol. 426, no. 6968, pp. 819–821, Dec. 2003, doi: 10.1038/nature02224.

[20] R. Herges, "Magnetic Properties of Aromatic Compounds and Aromatic Transition States," in *The Chemical Bond*, Wiley, 2014, pp. 383–420. doi: 10.1002/9783527664658.ch13.

[21] M. D. Peeks, T. D. W. Claridge, and H. L. Anderson, "Aromatic and antiaromatic ring currents in a molecular nanoring," *Nature*, vol. 541, no. 7636, pp. 200–203, Jan. 2017, doi: 10.1038/nature20798.

[22] K. Herawan Timotius and I. Rahayu, "QUALITATIVE ANALYSIS OF EUSIDEROXYLON ZWAGERI TEIJSM AND BINN SEED BY GC-MS AND LC-MS," *Int J Adv Res (Indore)*, vol. 8, no. 5, pp. 878–884, May 2020, doi: 10.21474/IJAR01/10998.

[23] R. A. Vacca, D. Valenti, S. Caccamese, M. Daglia, N. Braidy, and S. M. Nabavi, "Plant polyphenols as natural drugs for the management of Down syndrome and related disorders," *Neurosci Biobehav Rev*, vol. 71, pp. 865–877, Dec. 2016, doi: 10.1016/j.neubiorev.2016.10.023.

[24] A. A. Simaremare, N. Cahyo, and H. Indrawan, "Techno – economic study of utilizing CPO as fuel replacement for existing diesel power plant," *IOP Conf Ser Mater Sci Eng*, vol. 1098, no. 4, p. 042037, Mar. 2021, doi: 10.1088/1757-899X/1098/4/042037.

[25] L. Masoodi *et al.*, "An Overview on Traditional vs. Green Technology of Extraction Methods for Producing High Quality Walnut Oil," *Agronomy*, vol. 12, no. 10, p. 2258, Sep. 2022, doi: 10.3390/agronomy12102258.

[26] E. G. Giakoumis, "Analysis of 22 vegetable oils' physico-chemical properties and fatty acid composition on a statistical basis, and correlation with the degree of unsaturation," *Renew Energy*, vol. 126, pp. 403–419, Oct. 2018, doi: 10.1016/j.renene.2018.03.057.

[27] L. Qiao, R. Lewis, A. Hooper, J. Morphet, X. Tan, and K. Yu, "Using Natural Product Application Solution with UNIFI for the Identification of Chemicals Ingredients of Green Tea Extract," *Waters Application Note*, 2013.

[28] A. B. D. Nandiyanto, R. Oktiani, and R. Ragadhita, "How to Read and Interpret FTIR Spectroscope of Organic Material," *Indonesian Journal of Science and Technology*, vol. 4, no. 1, p. 97, Mar. 2019, doi: 10.17509/ijost.v4i1.15806.

[29] "Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)," Feb. 01, 2015, *ASTM International, West Conshohocken, PA*. doi: 10.1520/D0445-15.

[30] "Test Methods for Flash Point by Pensky-Martens Closed Cup Tester," Aug. 01, 2020, *ASTM International, West Conshohocken, PA*. doi: 10.1520/D0093-20.

[31] E. A. Rue, M. D. Rush, and R. B. van Breemen, "Procyanidins: a comprehensive review encompassing structure elucidation via mass spectrometry," *Phytochemistry Reviews*, vol. 17, no. 1, pp. 1–16, Feb. 2018, doi: 10.1007/s11101-017-9507-3.

[32] Q.-Q. Wang *et al.*, "Procyanidin A2, a polyphenolic compound, exerts anti-inflammatory and anti-oxidative activity in lipopolysaccharide-stimulated RAW264.7 cells," *PLoS One*, vol. 15, no. 8, p. e0237017, Aug. 2020, doi: 10.1371/journal.pone.0237017.

[33] S. Syahruddin, I. N. G. Wardana, D. Widhiyanuriyawan, and L. Yuliati, "The Effects of the Polarity and Molecular Dynamic Energy of Bamboo Activated Carbon on the Degumming Process of Calophyllum inophyllum Oil," *IOP Conf Ser Earth Environ Sci*, vol. 1097, no. 1, p. 012062, Oct. 2022, doi: 10.1088/1755-1315/1097/1/012062.

[34] R. B. Kinnel, "The Systematic Identification of Organic Compounds, 8th Edition By R. Shriner, C. Hermann, T. Morrill, D. Curtin, and R. Fuson. John Wiley & Sons, Inc., Hoboken, NJ. 2004. ix +723 pp. 21 × 32 cm. $102.95. ISBN 0-471-21503-1.," *J Nat Prod*, vol. 68, no. 2, pp. 309–310, Feb. 2005, doi: 10.1021/np058223w.

[35] Wardoyo, A. S. Widodo, W. Wijayanti, and I. N. G. Wardana, "The Role of Areca catechu Extract on Decreasing Viscosity of Vegetable Oils," *The Scientific World Journal*, vol. 2021, pp. 1–8, Jul. 2021, doi: 10.1155/2021/8827427.

[36] B. Waluyo, I. N. G. Wardana, L. Yuliati, and M. N. Sasongko, "The role of molecule cluster on the azeotrope and boiling points of isooctane-ethanol blend," *Fuel*, vol. 215, pp. 178–186, Mar. 2018, doi: 10.1016/j.fuel.2017.10.103.

[37] M. Pecovska Gjorgjevich, A. Andonovski, and J. Velevska, "Dielectric constant and induced dipole moment of edible oils subjected to conventional heating," *Macedonian Journal of Chemistry and Chemical Engineering*, vol. 31, no. 2, p. 285, Dec. 2012, doi: 10.20450/mjcce.2012.19.

[38] R. T. Moyo and M. Dewa, "The role of computational intelligence techniques in the advancements of solar photovoltaic systems for sustainable development: a review," *Renewable Energy and Sustainable Development*, vol. 8, no. 2, p. 52, Dec. 2022, doi: 10.21622/resd.2022.08.2.052.

[39] R. A. Felobes and M. Abadir, "Modeling the kinetics of pyrolysis of date seeds using artificial neural networks," *Renewable Energy and Sustainable Development*, vol. 10, no. 1, p. 123, May 2024, doi: 10.21622/resd.2024.10.1.811.

[40] R. N. Makadia and M. R. Dave, "Statistical analysis of industry scale up draft coal gasifier using response surface methodology for sustainable development," *Renewable Energy and Sustainable Development*, vol. 10, no. 2, p. 294, Oct. 2024, doi: 10.21622/resd.2024.10.2.940.

[41] H. Fang, K. Ni, J. Wu, J. Li, L. Huang, and D. Reible, "The effects of hydrogen bonding on the shear viscosity of liquid water," *International Journal of Sediment Research*, vol. 34, no. 1, pp. 8–13, Jan. 2019, doi: 10.1016/j.ijsrc.2018.10.008.

[42] A. K. Agarwal, "Experimental investigations of the effect of biodiesel utilization on lubricating oil tribology in diesel engines," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 219, no. 5, pp. 703–713, May 2005, doi: 10.1243/095440705X11239.

[43] "Mutu dan metode uji minyak sawit mentah untuk bahan bakar motor diesel putaran rendah," *Badan Standardisasi Nasional*, 2018.

[44] H. R. Ayub, W. J. Ambusso, and D. M. Nyaanga, "Remodelling operational parameters on the performance of a modified domestic pressure cooker," *Renewable Energy and Sustainable Development*, vol. 10, no. 2, p. 248, Sep. 2024, doi: 10.21622/resd.2024.10.2.921.