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CHARACTERIZATION AND SUITABILITY ASSESSMENT OF *CORDIA SEBESTENA* SEED OIL AS A BIODIESEL FEEDSTOCK

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ABSTRACT

Amid a rapidly expanding world demand for eco-friendly and renewable energy sources, researches interest on bio-fuels has significantly grown, including bio-diesels a favorable alternate fuel option towards conventional petroleum diesel; however, increased usage of some readily available and widely applied edible oils as feed stocks for producing biodiesel has been resulted with serious issues and problems concerning to global food security concerns, higher costs of production, the so-called food fuel nexus, that underlines the importance and the growing need for alternative non-edible feed sources in order for bio-diesel production be more economically. Therefore, as an alternative source to the highly researched oil seeds; Cordia sebestena may become an overlooked promising feed-stock because of it is non-edibility, better adaptability, and possibility oil producing nature, while limited amount of scientific investigations has been done on the examination, characterizing, fuel testing or biodiesel developing properties of Cordia Sebsetena seed oil , so far; therefore, it create a research gaps to carry out detailed investigation, here in this conceptual research paper, a detailed research assessment framework on extraction characteristics, Physicochemical characterization and fuel quality of Cordia sebsetena seed oil, including testing biodiesel production aptitude from Cordia sebsetena seed oil using innovative methods including but not limited to assessing suitable extraction methods for high rate of oil recuperation and determining their impacts on the physicochemical and biological parameters as biodiesel quality, in order to evaluate Cordia Sebsetena seed oil viability as an ideal

biodiesel source. Further steps include: assessing specific biodiesel quality characteristics such as density, viscosity, viscosity (40 o C), viscosity (100 o C), oil content, iodine value, saponification value, free fatty acid content, peroxide value, flash point, fire point and others that affect both the quality of biodiesel fuel and the conversion into biodiesel by transesterification; importantly studying of fatty acid constituents, (SFA vs UFA) profiles, from oil utilizing advanced techniques such as gas-chromatography-mass spectrometry (GC–MS); will be of the crucial importance to understand its relationship to the properties of resulting biodiesel(oxidative stability and cetane quality, low-temperature behavior). The resulting physiochemical and quality profiles will be ideally compared towards existing biodiesel feed-stocks; biodiesel fuel specifications by international organization in addition, future biodiesel production can be conceptualized via the biodiesel producing from Cordia sebsetena seed oil, and by especially exploring novel bio-refinery approaches for advanced heterogeneous assisted biodiesel formation that result in high conversion efficiency. Eventually; the most fundamental and vital result the current study is intended to get will create a sufficient basic background on Cordia sebsetena seed oil and acknowledge its potential to substitute conventional sources as non-edible biodiesel feed-stock thus will help in diversifying alternative renewable fuel resource bases as to reduces our world over reliance on crude and edible based oils resources as their availability may become increasingly problematic, promotes resource efficiency of unused biomasses and will bring us near to realize a cost effective clean energy and sustainability with zero emissions and greenhouse gas impact in future energy and transport sec.

KEYWORDS: *Cordia sebestena*, non-edible oil, biodiesel, fatty acid profile, physicochemical properties, renewable energy, feedstock assessment.

INTRODUCTION

Background of biodiesel development

The rapid rate of increase in global energy consumption, industrial expansion, transportation growth and economic development has led to continued reliance on fossil fuels, especially petroleum-derived diesel fuel which is still one of the dominant energy sources powering heavy-duty transportation, agricultural machinery, marine applications, and the electricity generation sectors, however, the excessive use of fossil fuels results in numerous environmental, economic and energy security concerns which are of high importance due to the limited reserve; changing crude oil price; geopolitical uncertainty and concerns over the

climate change. Global energy-related carbon dioxide emission levels reached a record high of approximately 37.4 GtCO2 in 2023 according to the International Energy Agency [IEA] (2024) thus highlighting the need for clean and renewable energy alternatives. Petroleum diesel combustion releases harmful substances that lead to air pollution through emission of GHGs, PM, CO, HC, SOx and NOx. These effects cause global warming, air pollution, destruction of ecosystem, and environmental concerns. This provides motivation for scientists and industries to develop sustainable renewable transportation fuels that can reduce the ecological impact of conventional diesel fuel consumption (Knothe & Razon, 2017). Among the potential renewable energy sources, biodiesel has been extensively researched as a fuel candidate due to its renewable source, low toxicity and biodegradability. Furthermore, it can be produced from vegetable oils, animal fats and waste oils via the transesterification process where the triglycerides present in the oil feedstocks is converted to FAMEs suitable for use as diesel fuels (Atabani et al., 2012). Biodiesel development has attracted huge amount of attention due to ability to reduce fossil fuel consumption, diversify agriculture and promote circular bioeconomy, especially with the use of non-edible oil sources that do not compete with the food sources. In general biodiesel offers several benefits over petroleum diesel oil, some of which are decreased lifecycle greenhouse gas emission, renewable carbon cycle, biodegradable, more environmentally friendly and lower persistence. Several researches have shown that the use of biodiesel produced from sustainable sources can decrease net CO2 emissions as most of the CO2 released during its combustion can be recaptured by the plants during their growth phase (Demirbas, 2009). Furthermore, biodiesel offers some desirable physicochemical properties that allows them to be used in existing C.I engines with modification or no modification when blended with conventional diesel oil hence portraying itself as technically viable alternative fuel to replace fossil diesel fuel gradually. Biodiesel blend fuel such as B5, B10, B20 are found to be compatible with the conventional commercial diesel fuel and engines (Hoekman et al., 2012). However, the issue of source sustainability needs to be addressed as fuel produced from edible oils can lead to competition with food and compromise land use and food security at high production scales; hence many research efforts are being diverted towards sustainable feedstocks such as non-edible sources and among these is Cordia sebestena seed oil. This paper investigates further in characterize and evaluate the suitability of Cordia sebestena seed oil for use as sustainable biofuel feedstock in a future energy development scheme.

Challenges associated with conventional biodiesel feedstocks

The evolution of biodiesel as a sustainable substitute to petroleum diesel biodiesel has heavily relied upon first generation biodiesel feedstocks sourced from edible vegetable oils, such as soybean oil, palm oil and sunflower oil, as these feedstocks are characterized by desirable qualities, namely high triglyceride content, well established agricultural production system, and relatively low transesterification conversion into fatty acid methyl esters (FAMEs). Unfortunately, the use of edible oil-based feedstocks on a large scale for biodiesel production has given rise to a number of sustainability challenges, including food security, environmental pressure and economic viability, leading to a constraint on the long-term application of edible oil-based feedstocks as a premium choice of biodiesel feedstocks (Atabani et al. 2012). One of the major types of biodiesel feedstocks utilized globally is the soybean oil, especially in those nations with significant soybean production sectors, owing to availability and a developed logistics network, along with acceptable composition as for biodiesel purposes (Rana et al. 2019). Nevertheless, its extensive use depends heavily on the allocation of agricultural land resource, fertilizers and irrigation, with an increased concern about land-use impact in agricultural production, with increased cost. Palm oil has gained recognition as highly resourceful biodiesel feedstock, thanks to excellent high productivity of oil and availability of the feedstock on commercial basis. However, the environmental issue, which is an enormous problem is associated with oil palm crop expansion, which in recent past is highly attributed to significant deforestation; loss of bio-diversity, emissions of greenhouses gases as results of land conversion, and several socio- issues that are strongly connected with the expansion of palm plantations (Meijaard et al., 2020). While sunflower oil offers beneficial qualities like relatively favourable compositions for biodiesel fuel (with moderate amount of saturated and adequate percentage of unsaturated fatty acids and with good oxidative stability), its commercial application on biodiesel feedstock ground faces significant limitation because it is largely known as edible oil resource, and that the production is seasonal and quite often depends on agricultural field condition, a part of it also competitive with edible oil market and use (Moser, 2009). Thus, increase the utilisation of edible oil derived from first generations biodiesel sources create significant sustainability concerns; namely the question food versus fuel (where redirection of agricultural production for energetic purpose could reduce food supplies and raise the cost for foods), environmental pressure of agricultural inputs such as irrigation, fertilizers and pesticides, and increased cost due to land utilization (Agarwal, 2007;). In first generation, source the use of a land, a relatively high amounts of irrigation water, pesticides, chemicals (fertilizers and soil

condition) and high energetic expenditure during land preparation , planting , harvesting, collecting, oil expressing and refining processes can make its environmental impact relatively high and this means that the relative fuel benefit can be seriously questioned (Chhetri et al. 2008). sAlso, the intensive cultivation, to cover production costs and the high cost of soybean and palm seeds for biodiesel production makes a significant competition between this type of fuel and food source (Knothe & Razon, 2017). For example, expansion of soy and oil palm to meet the diesel demands contribute directly to the pressure on the land resource and have led to several cases of land conflict and to large land clearing, habitat fragmentation, and destruction of bio-diversity and to increasing deforestation (Fargione et al. 2008). The economic problem in using biodiesel from the same plant seeds both for food and biodiesel production on sustainable basis is associated with price fluctuationality of such raw materials, processing costs, and dependency on subsidies and protectionism to support biodiesel business. Hence the issues mentioned above encourage researchers to turn attention toward the exploitation of second-generation biodiesel feedstocks such as plants producing edible oil, that will not directly enter to human competition (such as Jatropha curcas, Pongamia pinnata, Neem, and rubber seed etc.) (Gui et al. 2008) In this case study we will explore alternative unresearched plant seed with biodiesel feedstock properties as Cordia sebestena. The present study was performed to provide comprehensive understanding about suitability of various plant seeds in particular on their lipid contents, physicochemical analysis, as well as fatty acid profile composition and possibility to be utilized in sustainable and green future of biofuels production sector.

Potential of non-edible seed oils for biodiesel production

The rising demand of sustainable fuel for transportation and limitations associated with edible oil-based biodiesel stimulated abundant studies on non-edible seed oil as promising feedstocks for second generation biofuels because such resources potentially provide an opportunity to produce renewable fuels without a direct impact on food supply globally. Among non-edible oil bearing plants that were surveyed to be utilized for biodiesel, those that received special attention include Jatropha curcas, Pongamia pinnata, neem, Mahua and rubber seed oil considering the most favorable agronomic characteristics, high oil productivity, adaptation in different climates, and suitability for being converted into fatty acid methyl esters (FAMEs) by transesterification processes (Gui et al., 2008), Among different non-edible oil biodiesel plants considered herein, Jatropha curcas is among the most intensively studied oil crops. Its seeds contain oil between 30-40% generally, while it may

grow in semi-arid region using a minimum agricultural inputs (resource limited conditions), making it suitable for planting on Marginal & Degraded Lands where conventional food crops are of relatively poor productivity, although improvements such as planting density, plant spacing, fertilizer inputs, gene selection and economic valuation are expected for large-scale commercial production (Kumar & Sharma, 2008), Similarly, Pongamia pinnata (karanja) is also regarded as an important potential biodiesel crop with non-edible seeds that contains an oil amount between 25-40%, while its high capacity of nitrogen fixation, tolerance of drought conditions as well as an ability to be grown on wastelands and low fertile lands minimize the compete between its cultivation and food crops (Suresh et al., 2020). The seeds of neem (Azadirachta indica) are another important non-edible oil resources that are widely available in tropic and subtropics countries, resistant against environmental changes, and of high oil contents, and it's methyl ester, which possesses accepted fuel qualities after optimization of the catalyst chosen and free fatty acid removal (Atabani et al., 2013). Mahua (Madhuca longifolia) oil was investigated thoroughly; especially in South Asian countries, for having higher seed oil contents and availability all over the country that is Traditionally being utilized for non-food purpose only where biodiesel derived from its oils have accepted quality due to available amount of fatty acids suitable for conversion by transesterification (Balat & Balat, 2010) Additional, rubber seed oil obtained from Hevea brasiliensis is also being investigated to utilize it for biodiesel production, as rubber seed is waste from rubber plantation and the seeds contain substantial high oil content and if utilized to produce biodiesel could increase the resource sustainability and convert them into value-added renewable fuels (Yusup & Khan, 2010). Desirable properties of these non-edible oil feed stocks generally include high oil content that will benefit for the economics of biodiesel production process, availability on marginal lands that means no food crops will be displaced, and no competition with edible oil production. In fact, non-edible oil crop cultivation may be an additional source for cash economy as well as it can rehabilitate and restore the degraded soils. Moreover, the utilization of non-edible oil within a biorefinery concept may enhance more value-added products and improve its efficiency and sustainability performance (Chhetri et al., 2008). Within this broad scenario Cordia sebestena seed oil represents another promising but still under-investigated non-edible biodiesel feedstock and requires a complete characterization of its yield of oil and the physicochemical properties and fatty acid constituents to ascertain the performance of the advanced catalytic conversion processes for producing biodiesel.

Introduction to *Cordia sebestena*

The exploration of novel non-edible oil sources is emerging as a critical research area for sustainable biodiesel development, in this pursuit, Cordia sebestena, an apparently prospective but under-explored oil-bearing plant species that might contribute toward a diversification of renewable biodiesel feedstocks, has lately received attention, The family Boraginaceae, with many herbaceous and woody species dispersed within the tropical and subtropical regions of the globe, encompasses the woody evergreen tree Cordia sebestena L., globally termed the orange Geiger tree and native to tropical America, known for its hardiness and decorative value under various environmental settings such as a warm climate, coastal zones and moderate drought stress (Mabberley, 2017), Although natural distribution is limited to the Caribbean, Central and northern South America plus the neighboring continents/regions, the species has been introduced and planted in some tropical and subtropical nations for ornamental purposes attributed to its brilliant orange-red blooms as well as resistance to varying soil types, from sandy, porous but relatively low-nutrient soil to medium fertile soil (Staples & Herbst, 2005); taxonomically a small to medium evergreen tree, the fruit produces seeds which may bear valuable biochemical components, particularly the oil component that needs to be investigated further for use in industry; the plant has thus been subject of researches focused toward its ornamental, ecological and medicinal value rather than toward the characterizing oil property of its seeds as a viable feedstock for renewable biodiesel, which is a neglected area of research (Sahay & Yadav, 2021); in the case of Cordia sebestena seed oil bearing capacity, physicochemical characteristics, fatty acid content and oil extraction efficiency are identified factors that can determine the applicability of its oil for biodiesel production through transesterification; these factors include oil yield, free fatty acid (FFA) level, viscosity, iodine value, and the number of carbon and double bonds in the fatty acid chains for assessing oil quality and the number of catalysts required for optimal conversion (Atabani et al., 2013); more to that, non-edibility of the oil of Cordia sebestena obviates issues arising from competition with food resources and major sustainability aspects relating to food security, competition of land for production and price fluctuations of food crops (Gui et al., 2008); besides this, cultivation of Cordia sebestena for biodiesel production is in line with the current trend of a second generation biodiesel by-product being a non-food substance or biomass cultivated on marginal lands, thus making it an environmentally friendly and efficient energy source. Thus, despite its prospective properties, this plant remains a poorly researched biodiesel feedstock compared to others extensively studied, such as Jatropha curcas, Pongamia pinnata, neem and mahua; research

activities exploring the oil extraction performance, chemical properties, composition, catalytic behavior and fuel characteristics of Cordia sebestena seeds are crucial to determine its feasibility as a source of biodiesel feedstock.

Research gap and novelty

There has been considerable research on some selected non-edible oils, namely Jatropha curcas, Pongamia pinnata, neem, mahua oil and rubber seed oil for utilization as a prospective feedstock for biodiesel, as they are renewable, cheap and will not compete with food resources. However, some plant oils remained less investigated, such as Cordia sebestena which still awaits systematic research including extraction evaluation, physico-chemical characteristics, fuel properties of crude oil and potentiality for biodiesel. Cordia sebestena oil is a highly attractive choice due to lack of scientifically-proven research into its extraction efficiency, chemical composition, properties relevant to the production and use as a biofuel, and thus, need more scientific endeavors in exploring its biodiesel feasibility, as many novel plant-derived oils would be very useful alternative non-edible sources in the coming future. Biodiesel development so far showed that oil yield, free fatty acid content, acid value, viscosity, density, Iodine Value (IV), saponification Value (SV) and fatty acid distribution are important factor that influence transesterification efficiency, requirements for catalyst, quality, oxidation stability and performance in an engine (Atabani et al., 2013; Knothe & Razon, 2017). The present study offers new avenues as it provides a more detailed investigation on an underutilized non-edible resource, and establishes the data on the characterization on this oil suitable for sustainable second-generation bio-fuel including development of an integrated approach for evaluation as a potential biodiesel fuel for engines. It has been already indicated that Cordia sebestena oil could prove to be an environment-friendly sustainable fuel option for the nation. The characterization and molecular composition-fuel properties studies may enable to formulate methods of optimizing Biodiesel production using this oil. Additionally, such kind of studies on other potential non-edible oils will facilitate development of an efficient transesterification methodology even with heterogeneous catalyst or improved process for biodiesel production in the future. The novelty of this work is the detailed investigations for evaluating Cordia sebestena oil as viable non-edible feed-stock with enhanced understanding through an integrated framework covering oil extraction methods, precise chemical and fuel characteristics including a systematic approach for biodiesel production and characterization. The study addresses the

knowledge gap regarding utilization potential of this resource and will provide baseline for the comprehensive evaluation for environmental sustainability and economic viability.

Aim and objectives of the study

To evaluate the suitability of *Cordia sebestena* seed oil as a sustainable biodiesel feedstock through comprehensive physicochemical and compositional characterization.

Objectives

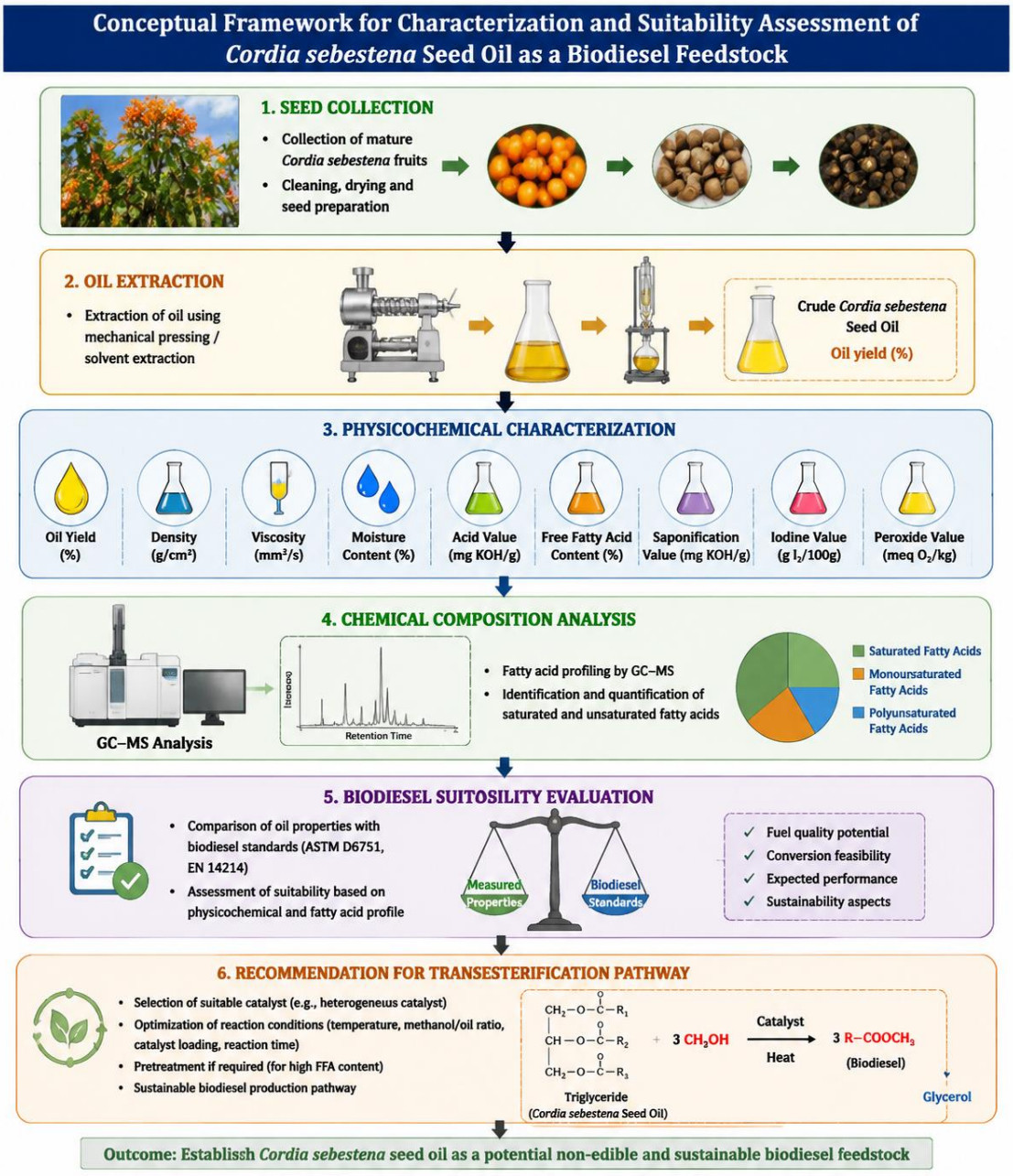
1. To analyze extraction potential and oil yield.
2. To characterize physicochemical properties of the seed oil.
3. To determine fatty acid composition.
4. To evaluate biodiesel production feasibility.
5. To compare oil characteristics with established biodiesel feedstocks.

Conceptual Framework of the Study

The conceptual framework of this study is proposed to provide a structured and scientific pathway to evaluate the sustainable non-edible biodiesel feedstock potential of Cordia sebestena seed oil by coupling the steps of feedstock preparation, oil recovery evaluation, physicochemical characterization, molecular composition analysis and biodiesel suitability assessment wherein the preparation step involves collection and selection of mature Cordia sebestena seeds from suitable source and subject it to cleaning, drying, size reduction and its readiness for oil extraction since qualities of extracted seed oil highly influenced by seed maturity, its moisture content, used extraction method, and storage conditions (Atabani et al., 2013), after which the oil recovery assessment stage is focused on determination of the oil recovery capability of Cordia sebestena seeds with use of any appropriate method like Mechanical pressing or Solvent- assisted extraction, using process performance such as yield, efficiency, and sustainability (Knothe & Razon, 2017) as significant indicators for commercialization perspective of potential feedstocks, The physicochemical assessment is of significant impact following oil recovery as it will shed the light on physicochemical characteristics of obtained seed oil and helps determine compatibility to biodiesel production processes and important parameters like oil yield, density, viscosity, moisture content, acid value, free fatty acid (FFA) content, saponification value, iodine value and peroxide value give clear indications on oil properties such as potential convertibility, fuel performance, storage stability, any pretreatment needed and characteristics in relation to biodiesel (Knothe & Razon, 2017) specifically, Oil yield indicates its production capability, viscosity and

density have an influence in the fuels atomization behaviour in the engine, oil moisture is crucial for a better transesterification reaction efficiency, whereas high value for either acid value or FFA has direct indications on requirements for the pretreatment of the oil, and at last saponification value, iodine and peroxide values give hints on composition of fatty acid, overall potential for oxidation, presence of mono- and di-unsaturated fatty acids and the degree of oxidation. Other than physicochemical the chemical composition characterization using sophisticated analysis tools such as GC-MS to get profiles of fatty acid composition of Cordia sebestena seed oil will be beneficial as they play a determining factor on many other properties like the cetane number, viscosity, and oxidative stability of its biodiesel (Moser, 2009), wherein the major SFAs or UFAs like Palmitic, Stearic, Oleic and Linoleic will provide molecular understanding on feasibility as second-generation biodiesel feedstock. Following chemical analysis, the coupled information from yield of extracted oil and physicochemical characterization along with GC-MS profile of fatty acids will further contribute to evaluate biodiesel Suitability Assessment by comparing the overall characteristics of obtained oil with standards requirements; such as those of ASTM D6751 and EN 14214, to determine its potential as second generation biodiesel feedstock in both renewable energy fuel sector and transportation. Furthermore, after a satisfactory analysis for yield, physicochemical properties and overall composition, a suitable transesterification pathway can be selected which might involve advanced catalysts and high process sustainable methodologies such as heterogeneous catalytic systems for easier separation and recycling. Overall, this conceptual framework aims to present a complete and a systematic approach to demonstrate the potential application of Cordia sebestena seed oil to serve as renewable non-edible alternative to diesel fuel. thereby determining its technical compatibility as a renewable fuel source, additionally, the framework considers the relationship between feedstock properties and future process optimization requirements by recommending suitable transesterification pathways involving catalyst selection, reaction parameter optimization, and possible pretreatment strategies, particularly emphasizing heterogeneous catalytic systems due to their advantages in catalyst recovery, reusability, reduced contamination, and improved process sustainability, the final stage of the framework involves establishing the overall potential of *Cordia sebestena* seed oil as a second-generation biodiesel resource by integrating scientific characterization, technological feasibility, and sustainability considerations, thereby providing a foundation for future experimental investigations related to catalyst development, reaction kinetics, life-cycle assessment, economic evaluation, and large-scale biodiesel production, ultimately transforming *Cordia sebestena* from an

underexplored non-edible plant resource into a potential contributor toward renewable energy diversification, reduced dependence on fossil fuels, and environmentally sustainable biodiesel development.



Above diagram showing the Conceptual Framework of the Study.

Feedstock Characterization Approach

The pretreatment of Cordia sebestena seed prior to oil extraction has been widely studied as this is the most important process for producing oil, which in turn contributes to quantity, quality and stability of recovered oil. Fresh seeds should first be cleaned to remove impurities

on their surface followed by controlled drying at an optimum temperature in order to remove the water content, control microbial decomposition and to increase the efficiency of oil recovery from seeds (Atabani et al., 2013). If seeds are not sufficiently dried, they could lead to the formation of unstable oil, penetration of solvent or any undesirable biodiesel conversion reactions. Low-temperature drying method is generally favorable to maintain the biological components such as the chemical stability and prevent possible oxidative deterioration of fatty acids and other oil contents (Atabani et al., 2013). After drying, the seeds are ground or milled to increase surface area to allow effective interaction with the solvent. Decreased particle size helps to improve solvent penetrations, facilitate breaking of cellular walls and subsequently enhances intracellular oil liberation upon extraction. Excessive grinding will cause increased energy consumption and possible oxidative deterioration of oil but optimum particle size can be considered through the investigation of the efficiency of oil recovery. (Moser, 2009). The extraction of Cordia sebestena seed oil can be done through solvent based extraction or by mechanical pressing. Solvent extraction method, usually with non-polar solvent such as n-hexane in the laboratory setting, is highly efficient and gives a higher extraction rate from the seeds (Gui et al., 2008). Mechanical pressing, on the other hand, does not involve chemical solvents and are more environmentally friendly, but it is comparatively less efficient on term of oil recovery. Factors to be considered for selected extraction method include the efficiency, the energy consumed and the cost. The rate of oil recovery can then be calculated in percentage by dividing the amount of oil recovered by the total mass of seed, and will contribute as a mean in identifying the potentials of a feedstock as biodiesel material. (Gui et al., 2008).

Physicochemical characterization

Physicochemical characterization of Cordia sebestena seed oil is an important part of evaluating it as biodiesel feedstock. The results of physicochemical characters of oil quality, conversion, catalyst selection and potential fuel performance would generally arise from the measured properties. Oil content is a key parameter to evaluate since it is an indicator for biodiesel production potential and cost-effectiveness of oil choice, as higher oil content is desirable for an efficient utilization of resources and cost reduction in development of industrial-scale biodiesel (Atabani et al., 2013). Acid value and Free Fatty Acid (FFA) content is a crucial parameter, because the two values represent the chemical quality of extracted oil and determine the need for a pretreatment step before transesterification, due to possible undesirable soap formation with alkaline catalyst with excess amount of FFAs. In other

words, if FFAs content is too high, soap formation will reduce biodiesel yield and separation. High FFA content oils are prone to preliminary esterification treatment prior to alkaline transesterification (Knothe & Razon, 2017). Saponification value of oil reveals informative information about the average molecular weight and the chain lengths characteristics of fatty acids; Higher saponification value shows that the oil generally has shorter chain length fatty acids and affects to biodiesel combustion characteristic and ester formation. Iodine value is important to predict the oxidation potential of biodiesel, whereas the chain unsaturation increases susceptibility to oxidation. Moderate unsaturation would confer good low-temperature biodiesel quality (Moser, 2009). Viscosity would be another parameter which in the initial phase has detrimental effect on atomization, fuel injection, combustion characteristics, whereas by transesterification it will reduce to improve fuel properties, Density would be beneficial for fuel injection characteristic, combustion characteristics as volumetric energy content and biodiesel engine performance as density is significant factor on volume of fuel injected in the chamber of diesel engine, hence the integrated analysis of oil content, acid value, FFA, saponification value, iodine value, viscosity and density of seed oil of Cordia sebestena give thorough consideration on the quality of the selected seed oil on its biodiesel production prospect (Atabani et al., 2013; Hoekman et al., 2012).

Fatty Acid Composition and Biodiesel Potential

In determining the biodiesel production capability of Cordia sebestena seed oil, fatty acid profile analysis constitutes one of the key factors since the structure and distribution of each fatty acid of the triglyceride would affect the property of the fuel: cetane number, oxidative stability, viscosity, cold-flow characteristics and combustion characteristics. Fatty acid profiling analysis is often carried out using the more sophisticated chromatographic techniques such as gas chromatography-mass spectrometry (GC-MS) where individual fatty acid components are characterized and quantified according to their retention time and mass spectral properties. Fatty acid methyl ester (FAME) analysis is widely employed in the studies of biodiesel production since the conversion to methyl esters will facilitate proper chromatographic separation and further comprehensive analysis of the fatty acid composition in the oil (Knothe & Razon, 2017). In this proposal characterizing Cordia sebestena seed oil using GC-MS-based FAME analysis, information regarding the percentage composition of saturated and unsaturated fatty acids can be obtained, and hence serve as indicators of the usability of this seed oil as a biodiesel feedstock. High percentage composition of saturated fatty acids i.e. C16:0 (palmitic acid) and C18:0 (stearic acid) is favorable for high cetane

number, good combustion quality, better oxidative stability of the fuel; however, their presence in too high proportions could result in unfavorable cold-flow properties due to increased melting point of biodiesel. Similarly, presence of unsaturated fatty acids such as C18:1 (oleic acid) and C18:2 (linoleic acid) is important as they will positively contribute to maintaining the fuel fluidity and combustion properties at low temperatures (Moser, 2009). It has been noted that, higher oleic acid content results in a desirable biodiesel feedstock with better resistance to oxidation than with high polyunsaturated oils, however moderate content of linoleic acid content helps to maintain suitable fuel fluidity and ignition characteristics; therefore, the evaluation of composition of fatty acids present in Cordia sebestena seed oil through GC-MS and FAME analysis will offer meaningful information regarding its potential for biodiesel production, its catalyst requirement and consequently the resultant fuel quality (Atabani et al., 2013).

Relationship between fatty acid composition and biodiesel properties

The relationship between fatty acid composition and biodiesel properties is very important for evaluating Cordia sebestena seed oil as a biodiesel feedstock since the chemical nature of an individual fatty acid, i.e., chain length, number of double bonds, and saturation position, determine and correlate strongly to fuel's chemical and physical properties, as well as engine's compatibility, ignition and combustion properties. Biodiesel from oils with balanced fatty acid profiles is desired for better fuel properties such as high oxidative stability and satisfactory engine operation performance. Fatty acids present the primary cause for differences in biodiesel properties, in specific: Oleic acid (C18:1), a monounsaturated fatty acid (MUFA) is often linked to improved oxidation stability because less amount of carbon double bonds in C-C chain decreases oxidizability of oil. An increment of oleic acid enhances oxidation stability, thereby the shelf-life of the biodiesel will be improved and stability due to peroxide reduction during prolonged storage period. Also, it improves biodiesel's resistance towards oxidation (Knothe & Razon, 2017). So, High oleic content is often favored in biodiesel feedstock to attain good oxidative stability and also satisfactory performance in cold operation conditions. Saturated fatty acids, such as palmitic acid (C16:0) and stearic acid (C18:0) affect biodiesel's ignition and combustion characteristics, as high saturated fatty acid content results in higher cetane number, better combustion quality, shorter ignition delay of ignition. However excessive content leads to increased viscosity due to high melting temperature at cold operating temperature (Moser, 2009). Polyunsaturated fatty acids such as linoleic acid (C18:2), linolenic acid (C18:3), affect biodiesel due to readily oxidizability since

the present double bonds at many positions provide potential reactive site for oxidation. Thus, biodiesel prepared from polyunsaturated sources have reduced oxidative stability resulting in increased fuel degradation, viscosity increase and formation of sludge, eventually lead to poor storage characteristics. Therefore. The biodiesel feedstocks extremely high in polyunsaturation are expected to have very poor storage stability, unless they contain antioxidants or to be further stabilize (Atabani et al., 2013). Thus, in present study, in case of evaluation of Cordia sebestena seed oil, knowledge on its fatty acid profile would supply some clues on assessing its value and potential on biodiesel production prior to the conversion process since ideal fatty acid profiles for fuel should generally contain considerable proportions of MUFA (especially oleic acid), a moderate amount of SFAs, and less polyunsaturated fatty acids (PUFA) to ensure satisfactory oxidation stability and good combustion. Therefore, the fatty acid composition analysis will be conducted in this study and reported to determine technical feasibility for Cordia sebestena seed oil biodiesel feedstock utilization.

Suitability Assessment for Biodiesel Production: Biodiesel Conversion Potential

In the aspect of evaluating the biodiesel conversion potential the evaluation of biodiesel conversion potential the evaluation of biodiesel conversion efficiency of the Cordia sebestena seed oil to produce biodiesel. Because successful conversion of triglyceride-based vegetable oil to biodiesel fuel. Success of esterification process of triglyceride oils to biodiesel fuels greatly depends on the physicochemical properties and compositions of feedstock, Free fatty acids (FFA), water content, catalyst and reaction condition. Transesterification which is a primary conversion process is considered to involve the conversion of triglyceride compounds present in the seed oil to form fatty acid methyl esters (FAMEs) and glycerol. The most widely applied alcohols include methanol (CH3OH) (Knothe & Razon, 2017). The transesterification of the Cordia sebestena seed oil is believed to occur readily when Cordia sebestena seed oil have acceptable physicochemical parameters such as moderate oil viscosity (viscosity of the sample expected at an optimal range) and acid value or low level of FFA, and proper proportions of saturated and unsaturated FAME that will render desired properties to biodiesel Fuel will promote the methyl ester formation in order to achieve better product yields and ease in separation. Thus, to maintain high fatty acids will undergo to esterification and then used to transesterification, high Free fatty acids, high Fames was converted to soap under conventional basic catalyzed transesterification and reduces the biodiesel productivity so prior treatment or a higher Catalyst amount may need. (Atabani et

al., 2013). Therefore The formation of Cordia sebestena seed oil will take place with the presence of oleic acid, linoleic acid, palmitic acid, and stearic acid that will in turn be directly related to fatty acid methyl ester in the formed Biodiesel. The amount of saturates and unsaturated fatty acids methyl esters in Cordia sebestena seed oil at reasonable range will yields a Biodiesel Fuel with good oxidation stability. Good cetane number, and favorable cosity, and engine performance in terms of fuel combustion (Moser, 2009). Advanced heterogeneous catalysts can improve Cordia sebestena seed oil transesterification efficiency, easily recovers after reactions and produces less waste than conventional catalyst so also can be recommended to produce Biodiesel Fuel with Cordia sebestena seed oil for better environmentally friendly approach due to low wastage (Atabani et al., 2013).

Biodiesel production pathway

The process flow for the conceptual production of biodiesel from Cordia sebestena seed oil includes oil characterization, pretreatment (if necessary), chemical conversion via transesterification with a heterogeneous catalyst, purification, and final fuel quality assessment. Cordia sebestena seed oil: A sustainable biodiesel precursor Seed oil characterization and evaluation The first step in the conceptual pathway is to characterize the raw seed oil. Cordia sebestena seed oil must be collected, dried, and mechanically processed in order to extract the oil efficiently. The quality characteristics of extracted Cordia sebestena seed oil, which include, but are not limited to, moisture content, viscosity, acid value, FFA concentration, and triglycerides composition, must be evaluated before biodiesel synthesis is attempted, as they have significant effects on catalyst performance, efficiency of the reaction, and overall methyl ester yield (Atabani et al., 2013). FFA testing, with its negative effects If an FFA concentration above a critical limit, typically set at 1% (v/w) or 2% (w/w) when using an alkaline catalyst, is identified in the feedstock Cordia sebestena seed oil, it should be tested and confirmed as FFA is responsible for significant catalyst deactivation. Such high FFA concentrations can cause severe issues in base-catalyzed transesterification of vegetable oil through saponification, which consumes the base catalyst (Bhuvaneswari et al., 2013), thereby producing unwanted soap that reduces catalyst effectiveness and complicates the separation of both biodiesel and glycerol, (Knothe & Razon, 2017). Pretreatment: Acid-catalyzed esterification When an FFA level in Cordia sebestena seed oil is found that significantly exceeds its specified limits for an alkaline catalyzed biodiesel synthesis reaction, oil must be pre-treated with an acid catalyst to carry out an acid-catalyzed esterification, which results in the FFA in solution being converted to FAME and reduces the acidity of the

oil, a process which aids in the biodiesel conversion efficiency and provides a biodiesel product that fulfills specifications (Marinkovi et al., 2016). This approach involves the conversion of free fatty acids to fatty acid methyl esters(s). Heterogeneous catalysis In a subsequent step, the Cordia sebestena seed oil that was refined in the pre-treating stage described above will react with methanol across solid catalysts to generate biodiesel consisting primarily of fatty acid methyl esters along with glycerol which precipitates as a co-product of the reaction process. The transesterification catalyst is typically produced from calcium, magnesium oxides and other solids which offer various advantageous attributes compared to homogeneous catalysts-most prominently are: ease of removal, increased re-usability and waste stream reductions-and its concentration, reaction time, reaction temperature, methanol-to-oil ratio, and other relevant operating variables must be optimize so that the concentration of fatty acid methyl esters (FMEs) produced is maximized while simultaneously diminishing total energy consumption. Process purification In addition to catalyst recovery after transesterification and the removal of water and FFAs-as aforementioned, when they exceed regulatory constraints of biodiesel fuel specifications, as established and codified into standards such as ASTM D6751 and EN14214, for use in the internal combustion engine within a motor vehicle-and excess methanol must then be retrieved. Cordia sebestena seed oil Biodiesel Production pathway.

Future Research Perspectives

These proposed future research perspectives for the successful development of Cordia sebestena seed oil biodiesel should consider integration of an advanced catalyst design, process intensification and sustainability assessment technologies, in order to convert this poorly explored non-edible oil source into a technically efficient and commercially viable renewable energy solution pathway where catalyst development is one of the future directions because of its significantly affect to transesterification, which highly dependent on the catalyst activity, stability, recyclability, environmental compatibility. In fact, novel CaO-based heterogeneous catalysts, e.g., derived from natural resources, modified calcium oxide systems should be investigated based on its unique strong basicity, low cost, good catalytic performance and reusability as well as structural modification, nanoparticle production and support integration to improve resistance of the catalysts to deactivation and enhancing biodiesel production from Cordia sebestena oil. Advanced metal oxides (MgO, ZnO, TiO, and mixed metal oxides) may also be considered to utilize their tunable surface properties and acid-base characteristics and catalytic behavior to achieve a high triglyceride conversion with

optimum parameters. Further research efforts are required to explore waste derived catalysts produced from various industrial wastes such as industrial residue, agricultural ash, waste eggshell or other calcium-rich biomass resources which are considered as a novel sustainable strategy to decrease catalyst production cost and to promote waste management. In additions to catalyst technology, the future studies have need to optimize the reaction conditions by investigating the reaction kinetics to understand the mechanism, rate-limiting steps, activation energies and equilibrium behavior during heterogeneous catalytic conversion of Cordia sebestena seed oil and to establish a well-qualified mathematical optimization techniques such as RSM to find the interaction between important reaction variables like methanol-to-oil ratio, catalyst loading, reaction temperature and time to reduce the reaction rate time, fuel consumption and operating cost. On the other hand, a continuous process for biodiesel production via packed-bed reactor, membrane reactor and other intensified flow-based technologies need to be studied to prevent drawbacks such as low productivity, under-utilization of catalyst and inability of scale-up of traditional batch reaction. Sustainability evaluation, including life cycle assessment (LCA) and techno-economic analysis, is crucial to establish the potential of Cordia sebestena as an alternative feedstock for second generation biodiesel. LCA, for instance, would cover impacts resulting from the entire value chain, ranging from land use, agriculture and feedstock transport up to biodiesel production and final use with greenhouse gas emissions. Furthermore, to enable the commercial viability of Cordia sebestena biodiesel against currently prevailing renewable alternatives as well as conventional petroleum-based fuels, economic evaluation covering aspects such as cultivation costs, oil yield and extraction efficiency, catalyst investment and operational cost and market penetration need to be addressed. Long-term cultivation studies would also play an important role to address crop yield performance over different locations, geo-climatic factors, ecological impacts as well as integration with non-arable land. Thus, an integrated approach combined with advanced catalyst development, process optimization and sustainability assessment is of great significance to turn Cordia sebestena seed oil into a truly sustainable feedstock of second-generation biofuel as well as helping achieve energy security and low-carbon policy globally.

CONCLUSION

As shown by the conceptual assessment, Cordia sebestena seems to be a promising non-edible oil for future biodiesel applications although it remains much unexplored as an alternative biodiesel feed. The growing interest toward developing second generation biofuels

to decrease reliance on edible oil feeds, combat food crisis and problems related to food security and unsustainable land-use practices supports utilization of non-edible oil feedstocks such as Cordia sebestena seed oil, yet more data are to be gathered prior to its application in biodiesel technology on industrial scale. Comprehensive characteristic analysis of Cordia sebestena seed oil are in order to determine its suitability for biodiesel production. Quality and quantity properties (physico-chemical, chemical and fuel properties) of oil extracted from Cordia sebestena seeds need to be scientifically analysed and reported, which are valuable sources of information for successful determination of appropriate pretreatment, extraction and catalyst techniques and overall performance of the fuel, as including oil yield, acid value, free fatty acid, viscosity and density. These parameters provide insights into effective of extraction, pre-treatment needs, selection of catalyst(s) and prediction of biodiesel efficiency and the quality (Atabani et al., 2013; Knothe & Razon, 2017). FAMEs and further analytical studies using techniques such as GC–MS of the fatty acid methyl esters (FAMEs) present in the Cordia sebestena oil seed are mandatory for the profiling of fatty acids. The degree of unsaturated fatty acids (UFA) to those saturated in FAMEs significantly affects crucial properties of biodiesel such as oxidative stability, cold-flow behaviour, cetane number, and combustion behaviour (Knothe & Razon, 2017). Based on appropriate correlation between physico-chemical properties and fatty acid profile of Cordia sebestena seed oil, an appropriate pathway might be selected for optimum conditions including transesterification, with priority to new trends as the heterogeneous catalyst assisted process. Utilizing this unused potential energy resource could improve diversification of energy carriers and contribute toward decreased CO2 emission, but its economic and environmental feasibility at large scales must be established as biodiesel feedstock through further studies. Therefore, the future research scope may encompass of studies on: improvement in process efficiencies by catalytic optimisation and reaction modelling, performing techno-economic analysis and LCA of process and feasibility of scaled-up production of Cordia sebestena cultivation.

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