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Optimized biodiesel production from *Carapa procera* and *Hura crepitans* seed oils using acid and basic catalysts derived from seed hulls

[Production optimisée de biodiesel à partir d'huiles de graines de *Carapa procera* et de *Hura crepitans* avec un catalyseur acide et basique dérivés de leurs coques]

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Abstract

The increasing demand for stocks. Trenewable energy sources has spurred interest in biodiesel production from non-conventional feedhis study investigated the production of biodiesel from oils extracted from Carapa procera and Hura crepitans seeds, utilizing acid and basic catalysts derived from their hulls. Oils from Carapa procera (HCP) and Hura crepitans (HHC) were transesterified with ethanol, employing an acidic catalyst for HCP and a basic catalyst for HHC, both synthesized from the respective seed hulls. The basic catalyst derived from Hura crepitans hulls demonstrated effective transesterification and maintained catalytic activity over multiple uses. High yields of ethyl esters were obtained for both Carapa procera (EEHCP) and Hura crepitans (EEHHC) oils. A B10 blend of EEHHC and fossil diesel met various ASTM D6751 specifications, including pour point, appearance, flash point, color, sulfur content, and density. The B10 blend also adhered to ASTM standards for viscosity, distillation, cetane number, copper corrosion, and carbon residue. However, B100 biodiesel from Carapa procera exhibited viscosity and acid number values slightly outside the standard limits, as did the viscosity of EEHHC, requiring further treatment, such as extended reaction time or blending with petrodiesel for viscosity adjustment. Based on these findings, Hura crepitans biodiesel can be blended with commercial diesel up to 10% by volume, meeting ASTM standards and making it suitable for use in diesel engines. Additional optimization is recommended for B100 from Carapa procera to ensure full compliance with biodiesel specifications.

Keywords: Carapa procera, Hura crepitans, Hull, catalyst, Transesterification.

Résumé

La demande croissante en sources d'énergie renouvelable a suscité un intérêt pour la production de biodiesel à partir de matières premières non conventionnelles. Cette étude se concentre sur le biodiesel dérivé des huiles de Carapa procera et de Hura crepitans, utilisant un catalyseur acide et basique issus de leurs coques. Les huiles de Carapa procera (HCP) et de Hura crepitans (HHC) ont été transestérifiées avec de l'éthanol, un catalyseur acide étant employé pour HCP et un catalyseur basique pour HHC. Ce dernier a montré une efficacité de transestérification et a conservé son activité catalytique après plusieurs utilisations. Des rendements élevés en esters éthyliques ont été obtenus pour les huiles de Carapa procera (EEHCP) et de Hura crepitans (EEHHC). Un mélange B10 d'EEHHC et de diesel commercial a satisfait aux spécifications ASTM D6751, notamment en ce qui concerne le point d'écoulement, le point d'éclair, la couleur et la densité. Toutefois, le biodiesel B100 de Carapa procera affichait des valeurs de viscosité et d'indice d'acide légèrement supérieures aux normes, tout comme la viscosité l'EEHHC. Cela nécessite un traitement supplémentaire, tel qu'un temps de réaction prolongé ou un mélange avec du pétrodiesel pour ajuster la viscosité. Sur base de ces résultats, le biodiesel de Hura crepitans peut être mélangé au diesel commercial jusqu'à 10 % en volume, répondant aux normes ASTM. Une optimisation supplémentaire est recommandée pour le B100 de Carapa procera afin d'assurer sa conformité totale aux spécifications du biodiesel.

Mots clés: Carapa procera, Hura crepitans, Coque, Catalyseur, Transestérification

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1. Introduction

Since Energy issues are widely debated globally due to demographic expansion, increasing urbanization, and the modernization of equipment, all of which contribute to a growing demand for energy services, primarily met by petrochemical resources. This has led to widening gaps between a supply that is becoming scarce and a demand that continues to rise (Rajpoot et al., 2023 ; Li, 2024). Access to energy remains a major challenge for populations in developing countries, especially in sub-Saharan Africa, where energy dependence on fossil fuels is estimated at nearly 39% of the total energy consumed. This dependence poses a constraint on the region's economic development, exacerbated by limited energy supply and rising demand in a context of increasing urbanization (Mulula, 2024). These imbalances are fuelling a global crisis, manifested in the depletion of fossil energy resources and environmental impacts, particularly greenhouse gas emissions. This underscores the urgent need to diversify energy sources. In recent years, numerous renewable energy sectors have emerged, spurred by government incentives (Ntumba et al., 2017 ; Sebayang et al., 2023). Biofuels, such as biodiesel, are seen as a viable alternative energy source that can reduce our reliance on fossil fuels, which have adverse effects on the environment (Mulula & Manoka, 2021 ; Oyekunle et al., 2024). Biodiesel is a biofuel derived from vegetable oil or animal fat through a chemical reaction known as transesterification, in which the oil reacts with an alcohol (methanol or ethanol) in the presence of an acid, base, or enzyme catalyst to produce either a Methyl Ester of Vegetable Oil (EMHV) or an Ethyl Ester of Vegetable Oil (EEHV), depending on the alcohol used (Fonseca et al., 2019 ; Mululu et al., 2022). This transesterification reaction allows the conversion of triglyceride oils into methyl or ethyl esters, with the aim of significantly improving their physicochemical properties. This is a commonly used method for the production of biodiesel, with high mass yields, generally between 98.5% and 99.4% (Lompo, 2008).

Given the growing interest in biodiesel production, this work aims to produce biodiesel from Carapa procera and Hura crepitans seed oils using heterogeneous acid and base catalysts synthesized from their hulls. These seeds were selected due to their widespread availability across tropical forests in Africa, particularly in the Democratic Republic of Congo, as well as their chemical properties that render them unconventional and unsuitable for consumption (Kouassi, 2023). Furthermore, the oil content in the seeds is estimated at 40-60% for HCP and 36.4-72.2% for HHC (Lankoandé et al., 2017 ; Ajala et al., 2023). This study is part of a broader effort to fully valorize oilseed species by using the almonds for oil production and the hulls, often considered waste, in catalysis. This demonstrates that organic waste from our garbage cans could serve as catalysts in the production of biofuels, used as alternatives to fossil fuels. A very important contribution to sanitation and environmental preservation.

2. Materials and Methods

2.1. Plant materials

The seeds of Carapa procera (figure 1a) were collected in the Kwilu province, specifically at the central market of Bandundu city (3°18'55''S, 17°23'08''E), while those of Hura crepitans (figure 1b) were gathered in Kongo Central province from a garden in the city of Kisantu (5°08'S, 15°06'E). All seeds were harvested in the Democratic Republic of Congo. They were then stored in the laboratory at room temperature, in a dry, light-protected environment, inside plastic containers.

Figure 1. a) Carapa procera seeds (Sanogo et al., 2013) *; b) Hura crepitans seeds* (https://www.shop-vegetable.com/wp-content/uploads/2019/09/hura_crepitans_seeds-e1637158302573.jpg)

2.2. Oil extraction from Carapa procera and Hura crepitans seeds

The seeds were crushed, and the almonds were then dried in an oven at 50 °C for 6 days for Carapa procera and at 60 °C for 48 hours for Hura crepitans before being crushed again. The resulting powders

were subjected to extraction by maceration at room temperature with petroleum ether (40-60 °C fractions obtained from the distillation of gasoline) as the solvent until the exhaustion of lipids, followed by macerating the residues (oilcakes) with the same quantity of petroleum ether (x2). The oilseeds were obtained after the removal of petroleum ether by rotavapor and dried in an oven at 60 °C for 4 hours (Owaba, 2024).

2.3. Synthesis of the acid catalyst from Carapa procera and Hura crepitans Hulls

The synthesis of the acid catalyst for Carapa procera hulls took place in two main steps, according to a methodology described by Abdelouahed. (2016) and Kabayo et al., (2019): calcination and activation by sulfonation, all preceded by a pretreatment which consisted of washing, drying, grinding and sieving.

In this experiment, a hermetically sealed aluminum foil containing 57.64g of *Carapa procera* seed hulls was placed in an oven for 4 hours at 400 °C. The residues obtained were stored in a desiccator. Then they were subjected to sulfonation with a volume ratio of sulfuric acid H_2SO_4 (98%) of 1g/15mL. Sulfonation at 90 °C for 5 hours in a three-necked flask, equipped with a magnetic stirrer at 500 rpm. The product obtained was washed with hot distilled water at 80 °C. Vacuum filtration followed, and the filtrate obtained was dried in an oven at 70 °C for 24 hours (figure 2a).

For the hulls of Hura crepitans the same procedure was used for its synthesis without going through sulfonation. After obtaining the powder from its crushed hulls, 15g was taken from the porcelain crucible and calcined at 800 °C for 4 hours. Then 2g of calcined powder dissolved while stirring in distilled water for 30 minutes (figure 2b).

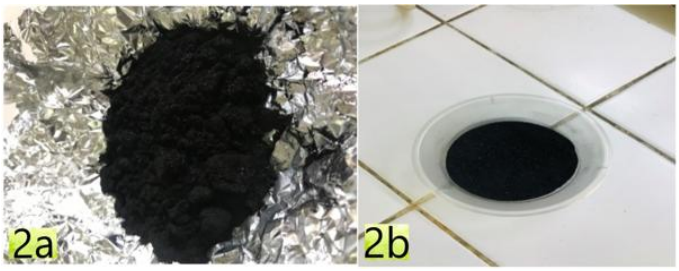

Figure 2. Activated hulls of (a) Carapa procera and (b) Hura crepitans

2.4. Transesterification reaction of Carapa procera and Hura crepitans

The transesterification reaction (figure 3) of Carapa procera and Hura crepitans oilseeds was carried out according to the experimental procedure described by Abdelouahed, (2016) and (Kabayo et al., 2019).

In this experiment, 50 mL of crude oil was placed in a round bottom flask of 500 mL to which 300 mL of ethanol and 10% by mass of catalyst were added, i.e. 4.123 g. The mixtures were heated under reflux for 5 hours at a reaction temperature of 70°C for HCP and refluxed for 4 hours at a reaction temperature of 80 °C for HHC, with an alcohol/oil molar ratio of 6/1 and then cooled to room temperature. The mixtures were filtered to recover the catalysts in order to evaluate the effectiveness of the catalyst by reusing it in the same reaction for HHC.

Then the mixtures were placed in a separatory funnel and left to settle for 24 hours. The biodiesel was extracted with petroleum ether, then washed with distilled water and dried with Na_2SO_4. After filtration, traces of residual solvents were eliminated by drying the biodiesel in an oven at 100 °C for 1 hour.

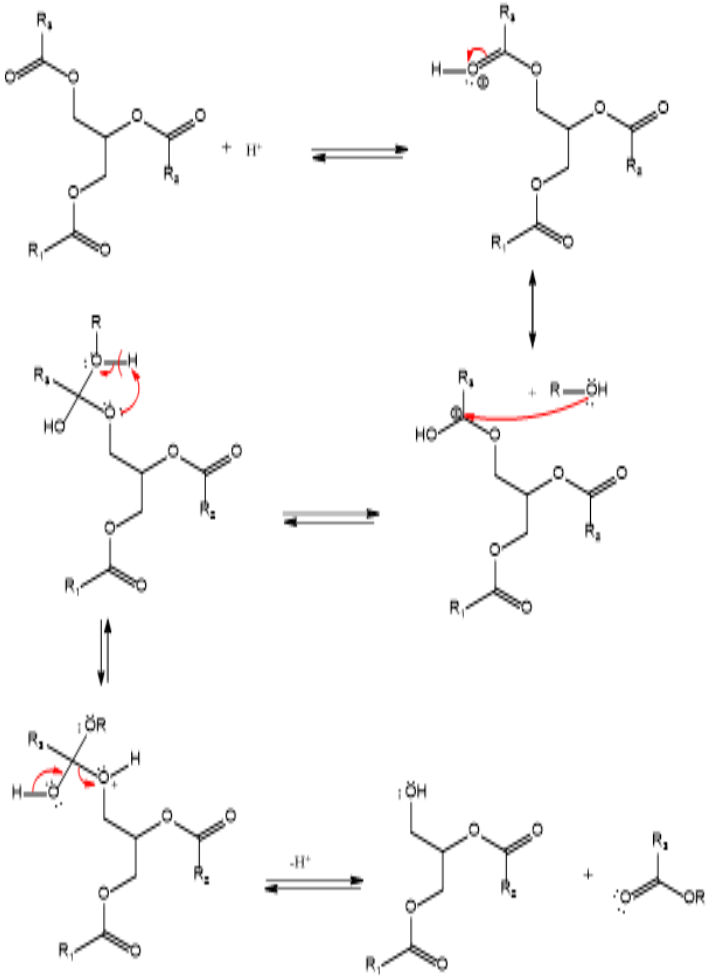

Figure 3. Mechanism of transesterification reaction by acid catalyst

The resulting biodiesels were analyzed for physicochemical properties using standards methods (ASTM and AFNOR) and the flowchart detailing the

differents steps involved in the transesterification reaction of *Carapa procera* oildseeds is presented in figure 4.

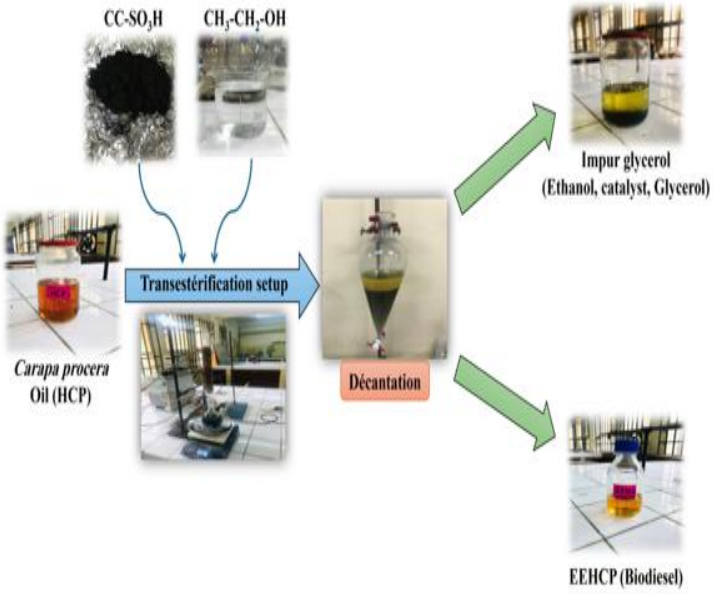

Figure 4. Flowchart of transesterification reaction from Carapa procera oildseeds

3. Results

3.1. Physicochemical Characterization of Carapa procera and Hura crepitans Oilseeds and Catalyst Synthesis from Their Hulls

The characterization of the extracted oilseed (figure 5a and 5b) was focused on the determination of the parameters listed in table I : acid index, saponification index, density, viscosity, according to AFNOR standard procedures. The oil content of *Carapa procera* (HCP) was 41.99%, acid number 18.79 mg KOH/g oil, density 0.917, viscosity 30.97cSt, saponification number 185.83mg KOH/g d oil and for Hura crepitans oilseeds (HHC) the acid number of 77.32mg KOH/g.

Table I. Yield and physicochemical characteristics of Carapa procera and Hura crepitans oilseeds

Characteristics	pH	Yield (%)	Acid number (mg KOH/g)	Saponification index (mg KOH/g)	Density	Viscosity (cSt)
C. procera	6	41.99	18.79	185.83	0.917	30.97
H. crepitans	8	49.1	77.32	ND	ND	ND

The catalysts had an acidic character for the sulfonated *C. procera* hulls (CC-SO_3H) with a pH 6 obtained after intensive washing after sulfonation, and basic for the H. *crepitans* hulls with a pH value of 8.

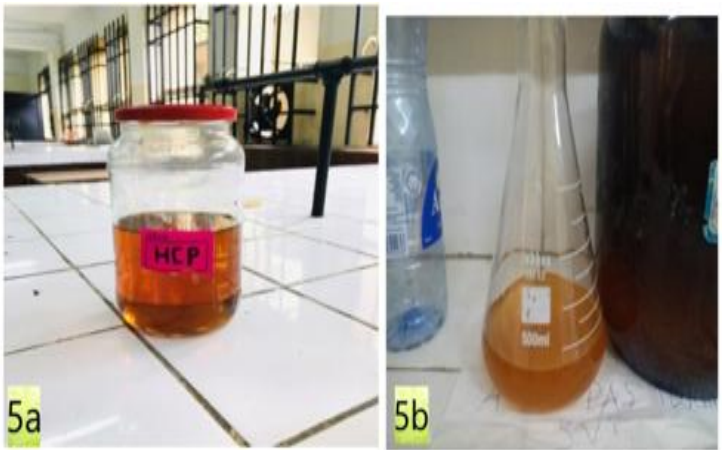

Figure 5. (a) Carapa procera oilseeds and (b) Hura crepitans oilseeds

3.2. Physicochemical Characterization of biodiesel produced from Carapa procera and Hura crepitans oilseeds.

For verification of the effectiveness of the transesterification reaction carried out on Carapa procera and Hura crepitans oil, as well as the quality of the biodiesel in comparison with international standards for biodiesels, the physicochemical properties summarized in table II were carried out.

The production of biodiesel yielded 78.81% for Carapa procera oil and 63.3% for Hura crepitans oil. The density of biodiesel derived from *C. procera* and H. *crepitans* was 0.866 and 0.886 respectively for B100, and 0.8360 for B10. The flash point of *C. procera* biodiesel was 110 °C. The viscosity, measured at 40 °C, was 16.96 cSt for *C. procera*, 6.088 cSt for H. crepitans (B100), and 3.7 cSt for B10. The acid value of C. procera oil showed a notable improvement, with a value of 1.45 mg KOH/g. Several other physicochemical parameters were determined for H. crepitans biodiesel, including the calculated cetane index, Pour point, total sulfur content, copper strip corrosion, color, and Conradson carbon residue. The corresponding values are presented in table II. For both types of biodiesel, the observed visual appearance was Clear and limpid.

Table II. Physicochemical characteristics of biodiesel from C. procera and H. crepitans oilseeds

Characteristics	EEHCP (B100)	EEHHC (B100)					EEHHC (B10)	Specifications ASTM D 6751 (B100)
Yield (%)	78.81	Nine	R	R	R	R	ND	-
		63.3	7.5	7.5	5.38	5.1		
Acid number (mg KOH/g)	1.45	ND					ND	0.80max
Density at 20°C **(ASTM D4052-96)**	0.866	0.886					0.8360	0.8064 -0.8866
Cetane number calculated	ND	ND					55.5	47min
Viscosity at 40°C (cSt) **(ASTM D445-04)**	16.96	6,088					3.7	1.9 – 6.0
Pour point (°C) **(ASTM D97-05a)**	ND	-33.0					-9	6 max
Total sulfur (%mass) **ASTM D4294]**	ND	0.034					0.020	0.05 max
Corrosion/Copper (coded) **(ASTM D130)**	ND	1a					1a	n°3max
Carbon residue (%m)	ND	ND					0.5	0.050max
ASTM color **[ASTM D1500-04a]**	ND	2.0					1.0	3.5 Max
Flash point (°C) (**ASTM D93-02a)**	110	ND					ND	130.0min
Appearance	Clear and limpid	Clear and limpid					Clear and limpid	-

4. Discussion

4.1. Physicochemical Characterization of Carapa procera and Hura crepitans Oilseeds

The HCP extracted in this study yielded 41.99%, while the yield for HHC was 49.1%. These values are lower than those reported in the literature (Silou, 2014 ; Silou et al., 2017 ; Nsomue et al., 2022). Previous studies highlight that several factors-such as the harvest period, extraction method, and environmental or edaphic parameters related to the species-can significantly influence the extraction yields of vegetable oils (Nonviho et al., 2014).

Moreover, we observed that the residual cakes remained slightly smooth to the touch after delipidation, indicating incomplete oil extraction.

The acid value was 18.79 mg KOH/g oil for HCP and 77.32 mg KOH/g oil for HHC. These high values reflect a significant presence of free fatty acids in the oils.

The saponification index, which correlates with the length of the fatty acid chains in the oil, was 185.83 mg KOH/g oil for HCP. This value aligns closely with previous findings (Silou, 2014 ; Oyelade et al., 2017; Nsomue et al., 2022).

The density of HCP was measured at 0.917, consistent with the 0.914 ± 0.004 reported in the literature (Silou, 2014 ; Lankoandé et al., 2017 ; Nsomue et al., 2022). However, several studies caution that high oil density negatively impacts diesel engine performance (Ntumba et al., 2017 ; Mulula et al., 2022 ; Paparao et al., 2022). A higher density increases the length of fuel jets, causing them to reach the bottom of the combustion chamber, potentially reducing combustion efficiency (Bettahar et al., 2016 ; Fadairo et al., 2024 ; Prahmana et al., 2024).

Viscosity, which is directly related to oil fluidity, was also evaluated. The viscosity of 30.97 cSt found in this study is comparable to the 34.22 ± 0.58 cSt reported by (Nsomue et al., 2022).

However, crude oils generally have high viscosities, which limit their direct application as biofuels. According to ASTM D445 standards, the acceptable viscosity range for diesel engine fuels is between 1.9 and 6.0 cSt, indicating that further processing would be required to improve fluidity for practical use (ASTM D445-04).

4.2. Synthesis of catalysts from Carapa procera and Hura crepitans hulls

The catalysts were tested in the conversion of free fatty acids from oils in the transesterification reaction to EEHCP and EEHC.

Acid number variation datawhich decreases from 18.79 mg KOH/g of oil to 1.45 mg KOH/g as a function of time of the reaction products for the proportion of the catalyst of 10% relative to the mass of oil showed that the catalyst presents a very appreciable catalytic activity.

Indeed, a conversion rate of 78.81% in EEHCP was achieved with 10% of the catalyst after 5 hours of transesterification reaction and 63.3% for EEHHC. These results attest to the almost certain effectiveness of the functionalization of the catalyst surface.

Abdelouahed et al. (2016) obtained a conversion rate of 95.42% was achieved with 5% after 3 hours of reaction at 65 °C by transesterifying date palm oil with a basic solid catalyst synthesized from nuclei of dates (Abdelouahed et al., 2016).

Kabayo in 2019 achieved a conversion of 90.28% by transesterifying palm kernel oil in the presence of a solid acid catalyst synthesized from coffee parchment (Kabayo et al., 2019).

This difference is probably due to the nature of the oil used and the different operating conditions. It should be noted that the conversion is favored by the extension of the reaction time, the choice of the catalyst and by the increase in the mass of the catalyst which increases the number of active sites in the reaction medium (Kabayo et al., 2019).

Evaluation of the effectiveness of our basic catalyst as shown in table II, reveals that our catalyst can transesterify oil efficiently despite its high acid number but also maintains good catalytic activity >55% even after 4 reuse . This can be explained by the fact that the catalyst is not very basic.

4.3. Physicochemical Characterization of biodiesel B100 and B10

The results presented showed that the biodiesel yields obtained are 78.81% for EEHCP and 63.3% for EEHHC according to the experimental procedure previously described in the literature. According to the literature, the acid transesterification reaction gives a yield of alkyl esters of the order of 95 to 99% (Ntumba et al., 2017 ; Mulula et al., 2022 ; Paparao et al., 2023). It turns out that in this reaction, the excess alcohol; the reaction time and the increase in temperature are important parameters for optimizing the yield (Hasannia et al., 2024 ; Vellaiyan et al., 2024). The yield is justified by the fact that the reaction time, temperature and volume ratio that we used do not allow us to optimize the yield. This agrees with the literature (Athar et al., 2022 ; Dwivedi et al., 2022 ; Banga et al., 2023).

The flash point of EEHCP is higher than that of the reference diesel (60 min). This makes this HCP-based biodiesel less dangerous to handle than diesel.

Biodiesel (EEHCP) has a viscosity of 16.96 cSt, which is well above the standards recommended by regulation 1.9-6.0 cSt (ASTM D445). However, this is extremely lower than that of the corresponding oil (30.97 cSt). This means that there will be overpressure in the engine as well as spraying difficulties in the combustion chamber. Biodiesel will have incomplete combustion. Studies have shown that high viscosity increases with increasing oxidation, number of carbon atoms and degree of saturation. Free fatty acids have a greater viscosity than their methyl ester counterpart. The high value of viscosity of ethyl esters of Carapa procera oil can be explained by the saturation of the crude oil.

For EEHHC on the one hand, the viscosity of B10 is lower (3.7 Cst) compared to B100 (6.088 Cst), which will allow better spraying of the product in the combustion chamber, and on the other hand it has slightly increased compared to diesel (3.5 Cst) but remained within the required standards.

The *C. procera* biodiesel produced has an acid value of 1.45 mg KOH/g. This value is greater than the maximum threshold recommended by ASTM standards (0.800 max). The rather high acid number result of biodiesel obtained in this study is probably due to the incomplete neutralization of the acidic heterogeneous catalyst used for the transesterification reaction. Nevertheless, the transesterification reaction significantly reduced the acid number which was 18.79 mg KOH/g for *Carapa procera* Oil from the start.

The density obtained after transesterification of HCP shows that there is a decrease from 0.917 (HCP density) to 0.866 (EEHCP density). This value is within the range of values set by ASTM regulations. For EEHHC B10 the density increased from 0.866 (B100) to 0.8360 (B10). The B100 therefore influenced the density but it remained within the set limits. This will allow good spraying of this fuel in the injector of the diesel engine. The pour point has changed from -33 °C (B100) to -9 °C (B10), but in both cases the fuel can be used in temperate and humid regions.

The quantities of total sulfur are very low for two biodiesels, 0.034 for b100 and 0.020 for b10. The total amount of sulfur for both biodiesels is significantly lower than the limit required by the international ASTM standard 0.05 max. The low total sulfur content could be explained by a better preparation and purification procedure for biodiesels. It should be noted that sulfur compounds in fuel smell bad and cause corrosion of the fuel tank and engine. In addition, sulfur compounds contribute to air pollution. Thus, these two EEHHC biodiesels present low risks for the diesel engine.

The calculated cetane index (CCI) of EEHCP, the value obtained in B10 (55.5) is slightly lower than that of diesel alone (57.5), but is within the required limitation (45 min). Which would leadsmooth operation of the engine, would facilitate cold starting, limit smoke, reduce noise, and improve engine efficiency with increased power. The cetane number characterizes the ignition time which is defined as the time elapsed from the moment the injection valve opens and pushes the fuel into the combustion chamber until the moment combustion begins; a low Cetane value means long ignition time.

For corrosion on copper of EEHCP, the value obtained is the same for B100 and B10 (code 1a). Being within ASTM D130 standards (ASTM D130), this means that B100 and B10 will not have a corrosive nature on the copper blade and therefore will not cause any damage to the tanks.

3. Conclusion

The primary objective of this study was to propose a biofuel derived from biomass as a sustainable alternative to fossil fuels, thereby offering a viable solution for energy production while maximizing the valorization of oilseed biomass. The research focused on the transesterification of Carapa procera and Hura crepitans oils using ethanol to produce ethyl esters of Carapa procera oil (EEHCP) and ethyl esters of Hura crepitans oil (EEHHC). Additionally, the shells of these seeds were utilized to develop heterogeneous acidic and basic catalysts.

The extraction process yielded 41.99% oil from Carapa procera and 49.1% from Hura crepitans. Transesterification results showed a yield of 78.81% for EEHCP and 63.3% for EEHHC. The transesterified Carapa procera oil exhibited improved physicochemical properties, with reductions in acid value, density, viscosity, and flash point, aligning closely with the ASTM D6751 standards for biodiesel. Similarly, the biodiesel blends (B100 and B10) derived from transesterified Hura crepitans oil demonstrated promising improvements. The basic catalyst obtained from Hura crepitans hulls proved effective, maintaining catalytic efficiency even after four reuse cycles.

Despite these advancements, some challenges remain. The acid value and viscosity of EEHCP, as well as the viscosity of EEHHC, do not yet fully comply with standard requirements. Additional treatments are recommended, such as extending the reaction time to further reduce the acid value and blending with commercial diesel to resolve viscosity issues.

To gain a better understanding of the phenomena observed in the field, future studies should assess the catalyst's effectiveness in more detail, particularly through in-depth elemental analyses and the use of advanced characterization techniques such as X-ray diffraction or scanning electron microscopy.

Research should also continue to optimize biodiesel yield and improve certain physicochemical properties of the final product through additional treatments, to ensure biodiesel compliance with international regulatory standards.

Furthermore, since this study was conducted at the laboratory level, it would be appropriate for future work to explore the feasibility of industrial-scale production, building on the promising performance observed with Carapa procera and Hura crepitans shells. This research should focus in particular on the stability of the catalyst, its reuse after several reaction cycles, as well as on the technical and economic evaluation of the large-scale production process.

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Conflicts of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical consideration

We are committed to respecting essential ethical principles in the writing of this article. We guarantee the originality of the content by rigorously citing our sources and excluding any form of plagiarism. The reliability of the information is ensured through rigorous verification. We respect the privacy of the individuals cited, with their consent where necessary. We strive to fairly represent the diversity of voices in a spirit of openness and respect.

Authors Contributions

P.K: Decisive contribution to the choice of the species Hura crepitans and the homogeneous catalyst, key elements of our experimentation.

A.M: Crucial contribution to the discussion of final product results, particularly the EEHCP and EEHHC, facilitating in-depth analysis and a better understanding of the issues.

I.M: Significant contribution to the development of the oil analysis protocol, ensuring the reliability and accuracy of the methods used.

A.M: Essential contribution to the formatting and discussion of the results, in addition to meticulous contributions to the bibliography, thus ensuring the clarity and consistency of the information presented.

T.K: Significant contribution regarding the agreement of the laboratory workers, as well as valuable contributions to the practical experimentation, thus strengthening scientific rigor.

K.K: Strategic input on prospects for improving the EEHCP and EEHHC final products, as well as an in-depth analysis of ASTM standards for biofuels.

K.W: Notable environmental contribution, enriching the bibliography of the work and providing a critical perspective on the ecological impact of our research.

J.N: Contribution to the project management, ensuring effective coordination and smooth management of the various phases of the project.

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Image Hura crepitans seeds. Disponible à : https://www.shop-vegetable.com/wp-content/uploads/2019/09/hura_crepitans_seeds-e1637158302573.jpg.

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