

Valorization of Cordia sebestena Biomass as a Heterogeneous Catalyst for Biodiesel Production from Non-Edible Seed Oils

VIJAYKUMAR TUMBAD¹, DR. K. S. KATAGI²

¹ Research Scholar, Department of Chemistry, Karnatak Science College, Dharwad, India

² Associate Professor, Department of Chemistry, Karnatak Science College, Dharwad, India

Abstract- The increasing focus on renewable and low-cost and environmentally clean options for global energy need the research on the valorization of plant-based waste biomass into functional materials which can assist the development of sustainable industrial processes in various fields. This interest is particularly pertinent for the field of biodiesel production whereby transesterification of the non-edible seed oil (specifically chosen for their distinction from food-grade vegetable oils) depends on the catalyst system. Cost, recovery and disposal options of the catalysts remain the most decisive factors for the viability of the entire process, and traditional homogeneous catalysts such as alkali hydroxides of potassium and sodium, despite being highly active and low cost to synthesize initially, suffer from several limitations due to their inability for recuperation and reuse, susceptibility to free fatty acids which leads to saponification, and formation of a significant amount of wastewater when neutralized and purified. While synthetic heterogeneous catalysts derived from petrochemical and mined mineral sources can overcome some of these challenges, their high initial costs of preparation, along with the associated environmental burdens, make it economically attractive to investigate the possibility of using discarded and underutilized plant biomass resources as an economic and eco-friendly alternatives for heterogeneous catalyst preparation, one example of which includes waste seed husks, shells and woody residues derived from the landscaping of ornamental trees such as *Cordia sebestena*. In this conceptual paper, a system for the valorization of *Cordia sebestena* biomass into calcination-based mineral-rich heterogeneous catalyst for non-edible seed oil transesterification is proposed, outlining how indigenous alkaline components like potassium, calcium etc, present within *Cordia sebestena* biomass can be thermochemically activated and structure-adjusted to produce catalyst with desired basicity, surface area and porosity for efficient fatty acid methyl ester conversion and to create a dual sustainability advantage. The proposed biomass-to-catalyst valorization scheme effectively converts otherwise worthless waste into valuable heterogeneous catalyst, which subsequently enables sustainable biodiesel

production from non-edible oil feedstocks, and simultaneously substitutes high cost and harmful traditional homogeneous catalysts and environmentally damaging synthetic heterogeneous catalysts. It is the aim of this paper to propose a novel biomass-catalyst-feedstock conceptual model which could serve as guidance for future experimental study in the preparation, optimization, and validation of biomass-derived catalysts.

Keywords: Biomass Valorization, *Cordia sebestena*, Heterogeneous Catalyst, Non-Edible Seed Oils, Transesterification, Waste-Derived Catalyst

I. INTRODUCTION AND BACKGROUND RELATED TO THE STUDY

The transport and industrial energy industries have placed growing emphasis in the past decade upon developing clean, renewable, and biodegradable replacements for conventional fossil diesel, as evidence by the growth of the global biodiesel market, estimated at around USD 61.52 billion in 2025, up from USD 57.91 billion in 2024 with a CAGR of 6.2% between the respective years, that is expected to continue expanding for the rest of the decade due to rising oil prices, tightening environmental regulations, and increased demand from the transport sector (ResearchAndMarkets.com, 2025). However, the performance of the most widespread transesterification catalysts: homogeneous, alkaline, is hampered by low separation of the solid and liquid catalyst, reusability, high cost and large volume of contaminated alkaline wastewater produced upon neutralization of excess alkali in the system, and saponification of tri-glycerides in the feedstock when free fatty acid content exceeds typical limits (Chouhan & Sarma, 2019). Consequently, increasing academic research has been dedicated to finding better catalysts; heterogeneous catalysts have been introduced, which

perform better than their liquid counterparts in terms of separation and reuse of catalyst, though they are still expensive whether made of solid mined or petrochemically produced mineral oxides (Chouhan & Sarma, 2019). As a consequence, much research effort has shifted toward the development and investigation of both organic and waste matter-based heterogeneous catalysts, which typically contain elements of alkali and alkali-earth metals such as K, Ca, Na and Mg which segregate from plant's organic and elemental C-O components to form oxides and carbonates upon combustion or thermal treatment to provide real base catalysis properties such as CaO, KO, MgO etc (Maroa & Inambao, 2021). Indeed, several plant and agricultural wastes have been extensively explored for their usefulness as hetero/base catalysts in transesterification reactions to yield biodiesel including wood ash, rice husks, banana peel ash and waste Brassica nigra ash, the latter of which is reported to be made of potassium (56.13 wt.%) and calcium (26.04 wt.%) as oxide, carbonate and chloride forms (Betiku et al., 2016). Despite the feasibility of these methods, there seems to be very limited published research to date that explores similar waste matter, as is the case for seed husk, shell and biomass from woody part of ornamental trees such as Cordia sebestena which are used for landscape gardening worldwide for its colourful flowers, they produce large volumes of waste matter that contain considerable quantities of potassium, calcium and other potential basic and acid catalyzing elements but for which no research has been reported. This paper will explore the potential application of waste from Cordia Sabena as a sustainable and cheap heterogeneous and basic catalyst for the transesterification of non-edible seed oil into biodiesel by providing a methodological and conceptual framework for the assessment.

II. STATEMENT OF THE PROBLEM

Despite a demonstrable technical feasibility and ever-increasing interest by the scientific community in biomass-derived heterogeneous catalysts as the environmentally friendly successors to current conventional homogeneous alkaline catalysts (which are still based on sodium and potassium hydroxide, generating alkali-containing polluted wastewater, losing catalyst after reaction and failing economical aspect in long term), the biodiesel industry is facing

severe lack of characterized low cost locally abundant biomass sources that can be reliably transformed into catalytically active substances, an absence that becomes more prominent because while several agricultural and horticultural wastes (cocoa pod husk, banana peel, karanja seed shell, various wood ashes etc.) have been successfully transformed into potent potassium- and calcium-rich heterogeneous catalysts yielding >90 to 98% biodiesel upon transesterification of non-edible and waste vegetable oils (Prajapati et al., 2023; Buasri et al., 2024) one common ornamental tree Cordia sebestena, grown throughout tropical & sub-tropical cities and horticultural areas, producing discarded seed husk, seed shells & pruned woody residues as horticultural waste, is yet to be explored even once as a potential candidate feedstock, hence its ash composition, mineral components, calcination characteristics and its catalytic performance upon transesterification remain undiscovered. Not only this, alongside Cordia sebestena there is a fundamental flaw regarding horticultural and ornamental trees which are less research concentrated than agricultural crops, despite producing a perennial stream of geographically distributed, largely wasted resource the disposal of which can cause pollution and release greenhouse gases without recovering any of the latent chemical value contained therein (Daimary et al., 2022). This problem: complete absence of data on Cordia sebestena as a feedstock for catalyst value addition and inadequate valorization of ornamental horticultural biomass as a source of renewable catalytic materials forms the essence of this conceptual paper that aims to propose a rational approach for producing catalytic heterogeneous from this wastage.

III. LITERATURE REVIEW

Organizing the reviewed literature by the composition of Cordia sebestena biomass, relative performance of biomass-derived heterogeneous catalysts, and attributes of non-edible seed oils as biodiesel feedstocks, the literature evidences through the year 2025 indicate that first, even though no specific study has documented the composition of ash or char obtained from Cordia sebestena specifically, research on related plants in the Cordia genus and in taxonomically similar ornamental and horticultural tree species indicated their seed, shell, and woody residue are lignocellulosic in composition and upon

combustion or calcination they behave in a similar fashion to other alkali earth-rich horticultural biomasses (e.g. See research on karanja seed shell ash which, following calcination and characterization by various techniques such as XRD, WD-XRF, SEM, FT-IR, BET and TGA, showed high K and Ca oxide content and is capable of catalyze soybean oil-transesterification to high yields(Prajapati et al.,2023)), thereby laying down a compositional and methodological precedent that may be reasonably extrapolated, conceptually, to *Cordia sebestena* biomass in the absence of direct analytical evidence; second, in reference to heterogeneous catalysts derived from biomass in general, a clear pattern emerges that plant-ash, biochar, and waste-shell catalysts perform on parity with or above commercial heterogeneous catalysts for biodiesel conversion (for example, see achievements such as banana peel ash being used to yield 98.95% biodiesel from soybean oil at room temperature owing to their alkaline and alkaline earth metals content (Betiku et al.,2018), combined banana peel and golden apple snail shell yielding CaO-KO effective catalyst for *Jatropha* oil biodiesel conversion via center-rotated-composite-design approach(Buasri et al.,2024),and pyrolyzed banana-peel biochar calcined as an alkali and alkaline earth rich catalyst for soybean waste cooking oil biodiesel conversion (Daimary et al.,2022) which together attest to the viability of biochar and calcined-ash catalysts in place of commercial heterogeneous catalysts);and third, pertaining to non-edible seed oils as biodiesel feedstocks, the evidence that *Jatropha* oil, karanja (*Pongamia pinnata*) oil and neem oil are the most researched in the region (India and South Asian countries) can be established with the information that *Jatropha* oil typically contains ~44.5% oleic acid, ~35.4% linoleic acid, ~13.0% palmitic acid, and ~5.8% stearic acid, with free fatty acids content that often require acid-catalyzed pre esterification to ensure a successful base- catalyzed transesterification reaction(Kumar & Sharma,2016). Karanja oil, on the other hand, shows similar or higher free acid content (up to 20%) which also demand dual esterification-transesterification processes; however, yields of up to 95.4% and above have been reported under optimal conditions (Naik, Meher, Naik, & Das, 2008). Furthermore, the investigation of blended non-edible feedstocks such as *Jatropha*, karanja, and waste cooking oil has illustrated that free fatty acid content

can be reduced to <1% with optimization techniques prior to a biodiesel conversion process that yields favourable outcomes and enhanced feedstocks flexibility (Husaini, Kadire, Verma, et al.,2025),thereby lending credibility to the catalytic compatibility of these feedstocks with heterogeneous-type base catalysts envisioned for utilization of *Cordia sebestena* biomass.

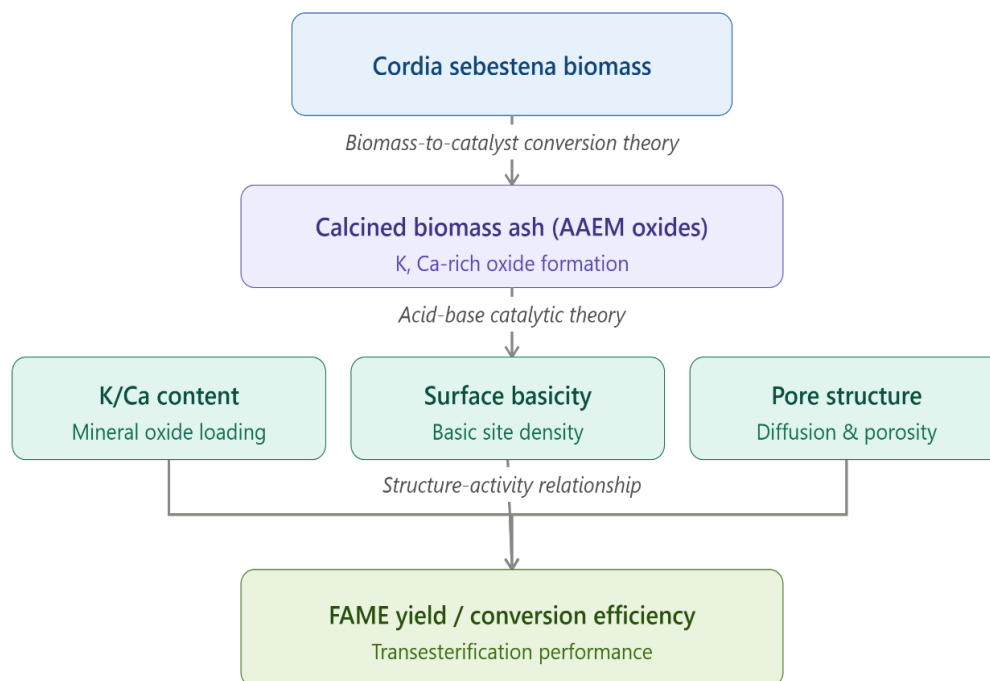
IV. THEORETICAL/CONCEPTUAL FRAMEWORK

The theoretical foundation of this concept paper is constructed upon three well-established, synergistically linked domains of theoretical and catalytic chemistry: (1) the biomass-to-catalyst conversion theory developed from both calcination and pyrolysis concepts; (2) a heterogeneous catalytic theory related to acid–base functionality; and (3) a structure–activity relationship framework focusing on how catalyst composition and textural properties correlate with reaction rate, or, in this case, catalytic activity. It begins with the biomass-to-catalyst conversion theory, which posits that in the high-temperature-induced transformation of lignocellulosic-rich plant biomass such as that found in seed husk, shell or woody fractions of *Cordia sebestena*, the organic carbon and hydrogen matrix is gradually removed by decarboxylation and decarbonylation reactions to generate a gaseous output, ultimately resulting in an inorganic mineral residue rich in alkali and alkaline-earth metal (AAEM) components-primarily potassium and calcium-and this mineral residue will recrystallize into catalytically viable oxide phases of CaO and KO after calcination temperatures are maintained within an optimal range, an intrinsic pathway already proven from diverse biomass precursors, including waste *Jatropha curcas* shells, for which iso conversional kinetic analysis under Kissinger's conditions was successfully used for determine definite temperature-regions necessary to decarboxylate precursor into oxide based active sites without over-sintering (Ribeiro et al., 2025). Building upon this conversion premise is the acid–base heterogeneous catalytic theory, by which it's elucidated the catalytic functionality of calcined biomass ashes that, will play its role as the transesterification catalyst due to the strong surface basophilic character of alkali-earth metal oxides as

CaO, MgO that are in equilibrium on the surface and facilitate abstraction of a hydrogen from methanolic molecules by formation of highly-reactive alkoxide species that are capable to attack the electrophilic carbonyl of the triglyceride molecules in a catalytic manner; that level of functional interaction is related with concentration and basicity strength which, as per review studies indicated, systematically differs based on nature of the parental oxide, being increased in the order of CaO, MgO and mixed alkaline-earth materials and, by reason of, the basicity strength was shown to positively correlate with deoxygenation (decarbonylation) efficiency over various biochar based catalysis including transesterification process (Fahmy et al., 2022). Finally, the structure–activity relationship part of the theory provides an insight into the catalyst design regarding FAME production by indicating that not only the mineral content should dictate catalytic yield but also an interdependence of K/Ca content, the basicity, and the pore structure should be considered, as illustrated by the comparative studies on CaOx-based heterogeneous catalysts (CaOx, calcined dolomite and Ca–dolomite–glycerol complex), yielding up to 99.4, 96.6 and 87.1% FAME, respectively, where basicity strength rather than the

amount of Ca plays a key role in determining catalyst efficiency along with structural characteristics of the catalysts (Chen et al., 2025); this concept further is supported by studies demonstrating that surface area gradually decrease as the calcination temperature increases even though increase completeness of carbonate/oxide transformation occurs by high calcination temperatures caused by particle sintering [16], hence, this conceptual work hypothesizes that K/Ca content, surface basicity and pore structure of optimally calcined *Cordia sebestena* heterogeneous catalyst are all collaboratively and quantitatively influencing FAME yield during transesterification of edible oil, providing the mechanistic and structural rationale for guiding catalyst development, testing, and optimization experiments in the scope of this present study.

The below diagram traces the full conceptual pathway: raw *Cordia sebestena* biomass converts into an AAEM-oxide catalyst through calcination/pyrolysis, acid-base catalytic theory shapes the resulting K/Ca content, surface basicity, and pore structure, and the structure–activity relationship links these three properties to final FAME yield.



Above diagram showing Theoretical/Conceptual Framework diagram related to the study

V. RESEARCH GAP

Despite the considerable, and rapidly increasing body of research devoted to biomass- and waste-derived heterogeneous catalysts for biodiesel synthesis, review of literature in this area uncovers three qualitatively, but strongly interdependent and significant gaps. Individually, and collectively these gaps clearly justify the present conceptual paper. Firstly, and critically, the entire subject area is devoid of even a single research paper dealing with *Cordia sebestena* biomass as a catalytic precursor. To contextualize, a growing number of relatively similar categories of ornamental, agricultural, or shell-based waste substrates, including; snail shells, egg shells, banana peel, karanja seed shell; have individually been thoroughly characterized, calcined and demonstrated as being efficient calcium or potassium rich heterogeneous catalysts that possess constant and high (% FAME) yields >90% (Macheli et al., 2025). Yet, to the best of present review, there exists to date, NO such data that pertains to the physical or chemical characterization, calcination optimization and activity assay of *Cordia sebestena* biomass in specific. Therefore, a crucial void remains as regards the overall mineral ash content (composition) and Transesterification capability (activity) of this biomass category, which is still unknown. Secondly, within the context of even the generally explored literature on the biomass-derived catalysts, a recurrent problem of the inability of the entire field to standardize biomass to catalyst conversion practices in general remains prevalent thereby seriously limiting comparability. Typically, research in this field shows wide variations in calcination conditions (temperature/time) as well as activation modes that range from, say, 773 K/3 hours; 1173 K/4hours, etc, based on the category of biomass investigated. However, lack of clearly defined methodologies in explaining systematically how these conditions affect surface area, basicity and FAME yield for a particular category of waste biomass hinders the generality of finding transferable between catalysts derived from categories of similar wastes (Macheli et al., 2025). The third deficiency, well documented but still not adequately addressed relates to the sustainability aspect of leached catalysts. Whilst a review has established that some of the waste shell derived catalysts can perform well for as long as 6-7 consecutive reaction cycles, catalytic site loss through

leaching remains a dominant catalyst deactivation mechanism for majority of the CaO- and K₂O-rich biomass derived heterogeneous catalysts and this may lead to contamination of the biodiesel fuel produced and continuous degradation of the catalytic performance throughout the reaction cycles; a degree of degradation which is generally inadequately presented via life-cycle analysis and continuous reusability studies for even the most widely studied categories, more so *Cordia Sebestena* (Aworanti et al., 2021). These three points; unexplored feedstock, standardized conversion protocols and unresolved leaching issues are the three mutually interacting drawbacks where the unique contribution of this conceptual article lies.

VI. OBJECTIVES OF THE STUDY

1. To characterize the composition, mineral content, and thermochemical properties of *Cordia sebestena* biomass (seed husk, shell, and woody residue), determining its potassium, calcium, and other alkaline-earth metal content as a precursor for heterogeneous catalyst development.
2. To synthesize and optimize a heterogeneous catalyst from *Cordia sebestena* biomass through calcination/pyrolysis, evaluating how activation temperature and duration influence resulting surface basicity, surface area, and pore structure, and characterizing the catalyst using XRD, BET, SEM-EDX, and FTIR.
3. To evaluate the catalytic performance of the *Cordia sebestena*-derived catalyst in the transesterification of non-edible seed oils (e.g., jatropha, karanja, waste cooking oil), optimizing reaction parameters (methanol-to-oil ratio, catalyst loading, temperature, reaction time) via RSM/CCD to maximize FAME yield.
4. To assess the reusability and leaching behavior of the synthesized catalyst across multiple transesterification cycles, quantifying activity retention, structural stability, and active-site leaching to determine its long-term sustainability and economic viability.

VII. METHODOLOGY RELATED TO THE STUDY

Since this is a conceptual paper, the proposed methodology follows as a roadmap to future empirical implementation rather than a past research endeavor starting from biomass acquisition and pre-treatment where a collection of *Cordia sebestena* seed husk, shell, and pruned woody residue is proposed to be sourced from the horticulture/landscaping waste and washed adequately to eliminate surface contaminants, sun- or oven-dried to a constant weight at approximately 105 C, then mechanically size-reduced (by grinding, sieving) to a uniform particle size for uniform thermal decomposition in a process that parallels the standard procedures known to exist in comparable shell/biomass precursor catalysts such as waste *Jatropha curcas* shell for which thermogravimetric analysis (TGA) for identifying optimum calcination temperature ranges for activation step for biomass precursor was first investigated prior to determining specific phases using conventional temperature calcination step (Tobo-Prez, Lapuerta, Canoira, Rokhum, & Piloto-Rodriguez, 2025), followed by calcination/activation step for the oven-dried/sieved biomass in a muffle furnace from ~600–900 C for 2–5 hours where the optimum temperature and time range is known to generally lead to the successful transformation of the organic carbonate precursor into active oxide phases, minimize the over-sintering/surface-area loss in waste shell/plant ash systems, and has been a standard procedure adopted across several studies (Mohammed, Alkhafaje, & Rashid, 2023). Physicochemical characterization is subsequently proposed for the calcined ash material including X-ray diffraction (XRD) for phase composition of crystalline metal oxides formed, Brunauer-Emmett-Teller (BET) gas physisorption for surface area/pore volumes, scanning electron microscopy coupled with energy-dispersive X-ray (SEM-EDX) spectroscopy for examining morphology and elemental compositions, Fourier transform infrared (FTIR) spectroscopy for analysis of functional groups and affirmation of oxides formation and TGA for evaluation of the thermal stability at various calcination temperatures as a similar technique employed on numerous ash-plant residue catalysts to evaluate calcination window for optimal oxide formation (Bhaskara Rao, Gnanaprakasam,

Manimaran, Balasubramanian, Kale, & Kilikeviius, 2025). The process step for transesterification reactions is proposed to comprise the addition of pre-selected quantities of non-edible seed oil and methanol along with calcined waste *Cordia sebestena* precursor catalyst into a batch reactor (three-necked flask) fitted with condenser and mechanical stirrer followed by heating in temperature-controlled bath at reaction temperature with continuous agitation. For optimization of the reaction, an RSM-CCD methodology with varying parameters to be analyzed are methanol to oil molar ratio, catalyst amount, temperature and time for the process that is known for comparable waste shell/plant ash catalysts where yields of more than 95% FAME have been shown to be obtained (Mohammed et al., 2023). And the major parameters to be determined through each of the proposed stages are percentage mass yields of FAME and percentage of reaction completion as determined through GC, the key criterion to evaluate the proposed theoretical approach of the work as done empirically.

VIII. DISCUSSION

When taken in their entirety, the abstract, introduction, literature review, theoretical framework, research gap, objectives, and methodology proposed in the prior sections of this conceptual paper collectively suggest that a carefully and intentionally valorized heterogeneous catalyst derived from *Cordia sebestena* biomass provides a promising conceptual case study for a cost-effective, sustainable alternative to traditional homogeneous and synthetic heterogeneous catalysts, with the case made for the biomass catalyst's potential strongly buttressed by data from comparable biomass-catalyst studies. Numerous other plant and agricultural waste sources ranging from coconut shells, rice husks, sugarcane bagasse, to tamarind seed have already been shown to be rich sources of silicon, calcium, potassium and carbon suitable for catalytically useful proportions. Agro-waste-derived heterogeneous catalysts that have been subjected to calcination with acid or basic activation commonly yield conversion rates of greater than 90% for transesterification (Damian et al., 2026), strongly indirectly implying that an identical method is conceptually useful for *Cordia sebestena* biomass despite the lack of specific study. At the same time, we must maintain scholarly rigor and note that despite

encouraging results and studies there remain ongoing technical and economical drawbacks to utilizing waste biomass as an industrial catalytic resource. Variables include inconsistencies in source material and precursor quality, significant technical challenges in scaling laboratory-specific calcination and acid/base-activation techniques for industry, and the high energy input and thus strong carbon footprint from high-temperature calcination processes. These challenges illustrate why despite a promising bench-top feasibility (similar to other, perhaps chemically or structurally analogous, waste sources), the process outlined in this proposal must be examined at a thorough techno-economic feasibility level such as those commonly completed on existing systems (Fung, Chai, & Ong, 2025). This has already begun on analogous waste-oil based biodiesels through calculation of both upfront cost, maintenance costs, and present value of net costs). Most importantly however, the circular-economy application proposed using ubiquitous discarded ornamental-tree biomass and waste, in contrast with purposely synthesized material, places this conceptually feasible framework at its core within the spirit of the circular bioeconomy where organic waste is transformed into a catalytic commodity – moving beyond a linear extract-make-dispose model and addressing major sustainability concerns that drive the circular bioeconomy. Biomass-derived heterogeneous catalysts have been proven capable of lowering biodiesel costs by up to 20% in comparison to synthetic catalysts while often still providing yields greater than 95% for the same process and thereby impacting overall life-cycle sustainability (Nweke-Maraizu et al., 2025). The circular-economy implications and the proven feasibility for biomass-ash catalytic performance provided here present a promising conceptual pathway to utilize discarded *Cordia sebestena* biomass but require specific empirical investigation-the precise study outlined in the preceding methodology section-before any claims of concrete feasibility or value under truly circular-economy principles can be substantiated for this particular biomass source.

IX. SIGNIFICANCE/IMPLICATIONS RELATED TO THE STUDY

The relevance of this concept paper spans academic, industrial-environment, and policy perspectives

starting with its academic relevance. A key academic benefit is its unprecedented extrapolation of biomass to catalyst conversion theory, acid-base catalytic theory, and structure activity relationships modeling to a fully uninvestigated biomass source, the result being a ready-made theoretical framework, a characterization procedure, and a RSM-CCD optimization design for future researchers intending to use *Cordia sebestena* as an input feedstock, without the need for the original reconstruction of conceptually equivalent theoretical framework and methodological methodology. This contribution fulfills a documented, persistent knowledge gap; there continues to be little or no research specifically connecting any of the multitude of under-utilized horticulture biomass feedstocks to a functional catalyst development application (Damian et al., 2026). From an industrial-environmental perspective, the potential impact of the conceptualization scheme is considerable; the work offers a true waste valorization pathway for what would otherwise be an untreated horticulture waste stream being sent to a landfill site or open burnt, diverting this mass of biomass to a higher-value catalytic resource. Indeed, it aligns with the accumulating evidence that, relative to a synthetic alternative, biomass derived heterogeneous catalysts can indeed provide up to 20% cost savings in biodiesel production, while maintaining greater than 95% conversion yields; this results in a demonstrably lower economic cost for the production of non-edible oil-based biodiesel compared to conventional methods (Nweke-Maraizu et al., 2025). Finally, from a policy perspective, the concept paper also has immediate relevance for the national biofuels target as well as waste utilization objectives, especially in the Indian context; despite setting a national target for biofuels blending at 5% by 2030, India still continues to produce >750 MT of agricultural residue each year, and >60 MT of municipal solid waste (the majority of which is un-utilized or openly burnt), a clear inconsistency between biomass availabilities and biodiesel blending targets which the government have highlighted as a structural constraint, necessitating diverse, locally sourced feedstock and catalysts under a revised National Policy on Biofuels and National Bioenergy Programme (Policy Circle, 2026). Hence, diversification of feasible, low-cost, waste to catalyst sources such as in this paper is fully consistent with the feedstock availability and waste utilization

objectives inherent within India's existing biofuels and circular economy policies, and positions this concept paper to contribute to the funding considerations and waste management decisions of researchers and policy makers interested in either catalyst development or horticulture waste management.

X. CONCLUSION

To conclude, this conceptual paper has presented a unified theoretical and methodological framework for bio-valorisation of *Cordia sebestena* biomass into a functional heterogeneous catalyst for transesterification of non-edible seed oils, systematically developed from the evidence-based introduction and literature review, through the integrated theoretical modeling framework which combines the principles of biomass-to-catalyst conversion theory, acid-base catalytic theory, and structure-activity relationship, to a well-defined three-fold research gap, a quartet of focused research objectives, and a proposed methodology encompassing biomass-to-catalyst transesterification comprising of collection of *Cordia sebestena* biomass, calcination optimisation, comprehensive characterisation of the synthesized heterogeneous catalyst, experimental design and optimization of transesterification process using RSM-CCD approach, followed by reusability testing of the synthesized catalysts. It is hypothesized, with support from documented performance of heterogeneous catalyst systems comprised of structurally and compositionally similar biomass-ashes and waste shell-like Catalytic Systems, a potassium-and calcium-rich bio-catalyst of low-cost value that exhibits similar transesterification efficiency compared to known catalysts generated from waste biomass-of agriculture which successfully reach above 90% transesterification, and yet, maintain good catalytic performance up to certain cycles. A key feature and therefore the overall contribution of this study to the literature will be the proposing of a previously undocumented biomass-catalyst pair, which, for once, does not necessitate the reinvention of the wheel to utilize biomass-derived catalysts, the fundamental structure of such a category of catalysts and their fundamental principles being well explored. The proposed approach toward valorization of *Cordia sebestena* supports diversion of unmanaged

horticulture wastes to valuable catalytic resource, leads to low-cost biodiesel production with efficient circular economy integration compared to use of heterogeneous catalysts of another sort. Considering the recent and existing work on biomass as a resource material in the fuel sector and environmental pollution aspect, its usage in indigenous technology, where in; various renewable sources have been explored, which includes biomass of agricultural and horticultural sector, the results from the present study can become contributing source in fulfilling India's sustainable fuel goals and national biofuel mission policy at par with utilization of agro-residues. Though the results mentioned in the paper are tentative as the laboratory synthesis, analysis, and optimization study is still underway, a coherent, theoretically justified and operationally feasible framework for bio-transformation of unmanaged horticulture waste of *Cordia sebestena* into a scientifically verified, and industrially significant heterogeneous catalyst is nevertheless built herewith.

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