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EXPERIMENTAL PERFORMANCE, COMBUSTION AND EMISSION ANALYSIS OF ETHANOL–KARANJA BIODIESEL–DIESEL TERNARY BLENDS IN A COMPRESSION-IGNITION ENGINE

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ABSTRACT

This paper presents an experimental research framework for evaluating ternary blends of ethanol, Karanja biodiesel and mineral diesel in a single-cylinder compression-ignition engine. Four fuels are considered: neat diesel, K20E5D75, K20E10D70 and K20E15D65, where K, E and D denote Karanja biodiesel, ethanol and diesel volume fractions. The study compares brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen (NOx) and smoke opacity over 20–100% engine load at 1500 rpm. Biodiesel acts as a renewable oxygenated component and can also improve the stability of diesel–ethanol mixtures, while ethanol reduces viscosity and contributes additional fuel-bound oxygen. In the representative dataset developed for the proposed methodology, K20E10D70 provides the highest BTE, whereas increasing ethanol generally raises BSFC because of lower fuel heating value. CO and smoke decrease as oxygenated-fuel fraction increases; NOx remains operating-condition dependent. The paper includes fuel characterization, test-rig configuration, experimental procedure, performance equations, uncertainty requirements, comparative graphs and research recommendations. Numerical values presented as experimental results are illustrative and must be replaced with actual laboratory observations before publication.

KEYWORDS: Karanja biodiesel, ethanol, diesel, ternary blend, CI engine, BTE, BSFC, combustion, emissions, smoke.

1. INTRODUCTION

Diesel engines are widely used because of their high thermal efficiency and durability, but their dependence on petroleum and emissions of particulate matter and nitrogen oxides motivate the development of renewable fuels. Biodiesel derived from non-edible Karanja oil is particularly relevant to India. Ethanol is renewable, oxygenated and highly volatile, but its low cetane number, lower heating value and limited stability in diesel can create ignition and miscibility problems.

A ternary diesel–biodiesel–ethanol formulation can balance these properties. Published reviews report that biodiesel can improve the physicochemical characteristics and stability of diesohol blends, while the oxygen in biodiesel and ethanol can suppress particulate formation. However, BSFC, CO, HC and NOx depend on blend ratio and engine condition. This study therefore proposes a controlled experimental comparison focused on Karanja biodiesel and ethanol.

2. Literature Review

Shahir et al. reviewed diesel–biodiesel–ethanol/bioethanol ternary blends and concluded that biodiesel can act as a useful blending component for stabilizing diesel–ethanol mixtures and improving their fuel properties. Their synthesis found strong potential for particulate-matter reduction, while gaseous-emission trends varied with engine operation.

A 2022 review of alcohol–biodiesel–diesel fuels concluded that oxygenated ternary blends can be used in compression-ignition engines with relatively small modifications, although their lower calorific value can increase fuel consumption. Another detailed review found that alcohol addition tends to lengthen ignition delay because of lower cetane quality and high latent heat, while improved spray atomization and oxygen availability can enhance combustion and reduce CO, HC and PM under many conditions.

For Karanja specifically, a 2021 Fuel study tested K20, K25 and K30-type Karanja biodiesel–ethanol–diesel blends in a four-stroke single-cylinder diesel engine at 1500 rpm and 210 bar injection pressure. The authors identified Karanja biodiesel up to 20% with ethanol up to 10% as a suitable range and used Taguchi/grey-relational optimization for BTE, BSFC, EGT and gaseous emissions. This provides a strong basis for selecting K20E10D70 as the central ternary blend in the present framework.

3. Fuel Blend Preparation

Table 1. Proposed fuel blends by volume.

Fuel code	Karanja biodiesel	Ethanol	Diesel	Purpose
Diesel	0%	0%	100%	Baseline
K20E5D75	20%	5%	75%	Low ethanol ternary blend
K20E10D70	20%	10%	70%	Literature-supported central blend
K20E15D65	20%	15%	65%	Higher ethanol comparison

Anhydrous ethanol should be used to minimize phase-separation risk. Each blend is prepared volumetrically, mixed thoroughly and visually monitored for haze or separation before testing. Density, kinematic viscosity, calorific value, flash point and cetane-related ignition quality should be measured using applicable ASTM methods.

3.1 Representative Fuel Properties

Table 2. Typical literature ranges; actual test-fuel properties must be measured.

Property	Diesel	Karanja biodiesel	Ethanol
Density at 15°C (kg/m³)	830–850	~870–890	~789
Kinematic viscosity (mm²/s)	~2–4.5	~4–5	~1.2
Lower heating value (MJ/kg)	~42–43	~37–40	~26.8
Cetane tendency	High	Moderate–high	Low
Oxygen content	Very low	~10–12%	~34.8%

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4. Experimental Setup and Methodology

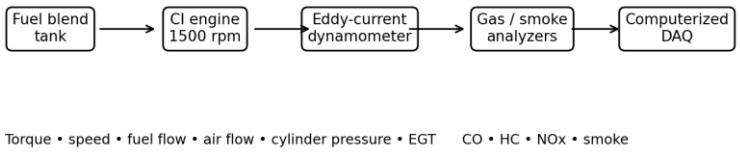

Figure 1. Proposed experimental test rig for ternary-fuel performance and emission analysis.

Table 3. Recommended engine and instrumentation details

Parameter	Representative test specification
Engine	Single-cylinder, 4-stroke, water-cooled CI research engine
Rated power	~3.5–5 kW
Operating speed	1500 rpm
Loading	Eddy-current dynamometer
Injection pressure	210 bar representative
Compression ratio	Fixed or VCR; report actual setting
Load points	20, 40, 60, 80 and 100%
Fuel flow	Burette/gravimetric system
Cylinder pressure	Piezoelectric pressure transducer
Crank angle	Crank-angle encoder
Emissions	5-gas analyzer + smoke meter

.4.1 Experimental Procedure

The engine is first operated on diesel until coolant and exhaust temperatures stabilize. Baseline observations are recorded at each load. The fuel line is then flushed and the selected ternary blend is introduced. For every test point, speed is maintained at 1500 rpm and torque, fuel-consumption rate, air flow, exhaust temperature and emissions are recorded after steady conditions are achieved. Cylinder-pressure data should be averaged over at least 100 consecutive cycles. Each fuel–load point should be repeated a minimum of three times.

4.2 Performance and Combustion Equations

Brake power: $BP = 2\pi NT/(60\times1000)$, where N is rpm and T is torque in N·m. Brake specific fuel consumption: $BSFC = \dot{m}f/BP$. Brake thermal efficiency: $BTE = BP/(\dot{m}f\times LHV)$. The apparent heat-release rate may be obtained from cylinder pressure using the first-law expression $dQ/d\theta = [\gamma/(\gamma-1)]p(dV/d\theta) + [1/(\gamma-1)]V(dp/d\theta)$, with suitable corrections for heat transfer when detailed combustion analysis is required.

5. RESULTS AND DISCUSSION: Engine Performance

5.1 Brake Thermal Efficiency

BTE rises with load for all fuels because the relative influence of friction and heat losses decreases. In the representative dataset, K20E10D70 produces the highest full-load BTE of 31.5%, compared with 30.0% for diesel. The intermediate ethanol fraction can improve mixture preparation and oxygen availability while retaining sufficient ignition quality from diesel and biodiesel.

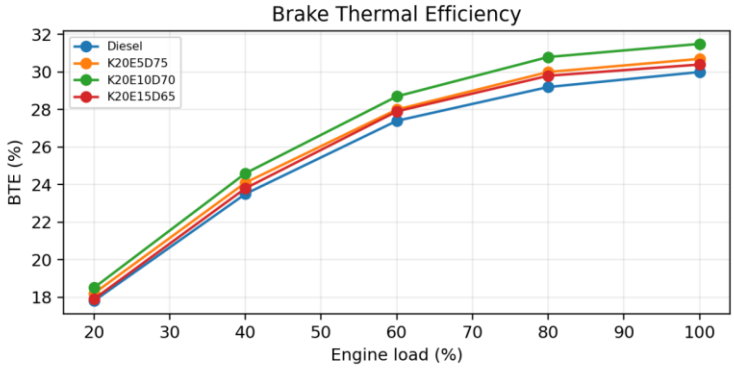

Figure No 2. Representative BTE variation with engine load.

5.2 Brake Specific Fuel Consumption

BSFC decreases as load increases, but the ternary blends generally consume more fuel mass than diesel because both ethanol and biodiesel have lower heating values. At full load the representative BSFC values are 0.28 kg/kWh for diesel, 0.29 for K20E5D75, 0.30 for

K20E10D70 and 0.32 for K20E15D65. Thus, thermal-efficiency improvement does not necessarily imply lower mass fuel consumption.

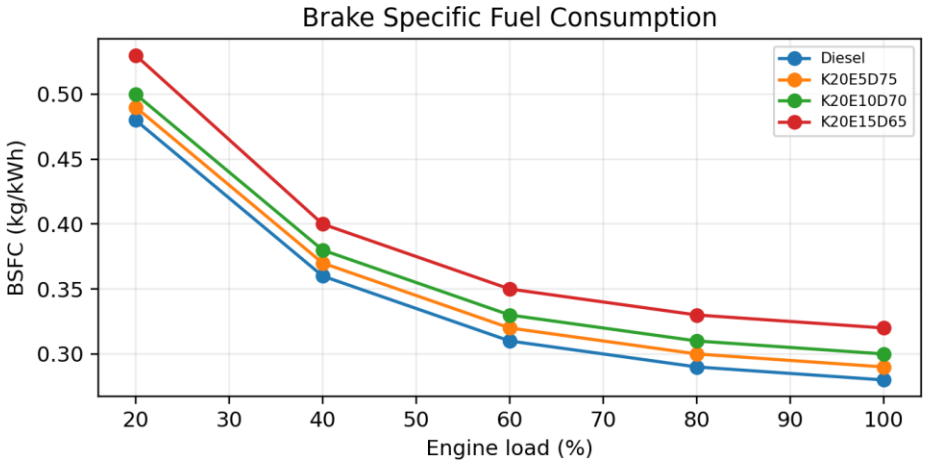

Figure 3. Representative BSFC variation with engine load.

5.3 Exhaust Gas Temperature and Combustion Interpretation

EGT increases with load because more fuel energy is released per cycle. Increasing ethanol fraction lowers the representative EGT because ethanol has a high latent heat of vaporization and lower heating value. Its low cetane number can also lengthen ignition delay, increasing the premixed fraction of combustion. Literature reviews report that alcohol addition can increase ignition delay and maximum heat-release rate, while biodiesel in the ternary blend partly offsets poor ignition quality.

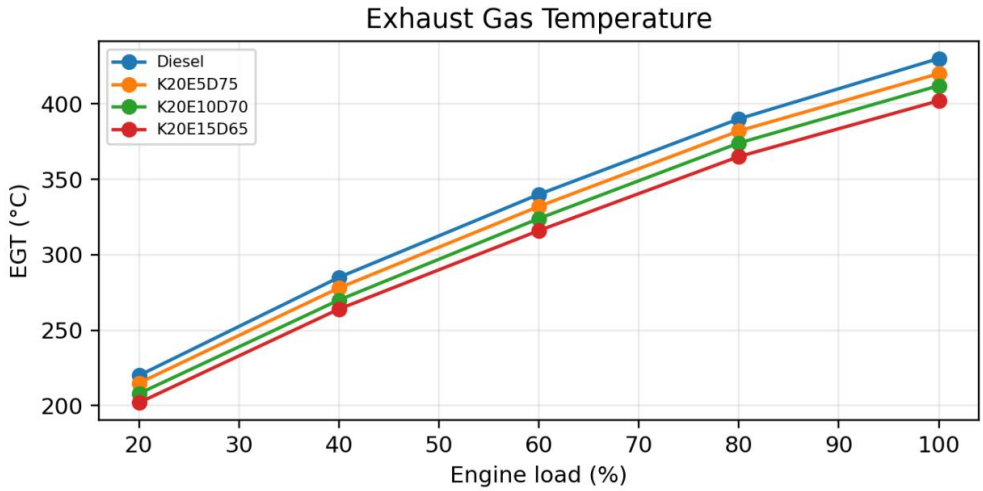

Figure 4. Representative exhaust gas temperature.

5.4 Expected Cylinder Pressure and Heat-Release Rate

A publication-quality experiment should record in-cylinder pressure versus crank angle for all blends. Ethanol can increase ignition delay, allowing more fuel to accumulate before ignition and producing a sharper premixed heat-release peak. However, high latent heat can lower local temperature and peak pressure. The net response depends on injection timing, compression ratio, ethanol fraction and biodiesel cetane quality. Therefore, pressure and heat-release plots should be based only on actual pressure-transducer measurements rather than invented curves.

6. Emission Characteristics

6.1 Carbon Monoxide

CO generally increases with incomplete oxidation and locally rich combustion. The oxygen present in biodiesel and ethanol can improve oxidation, so the representative ternary blends show lower CO than diesel, particularly at high load.

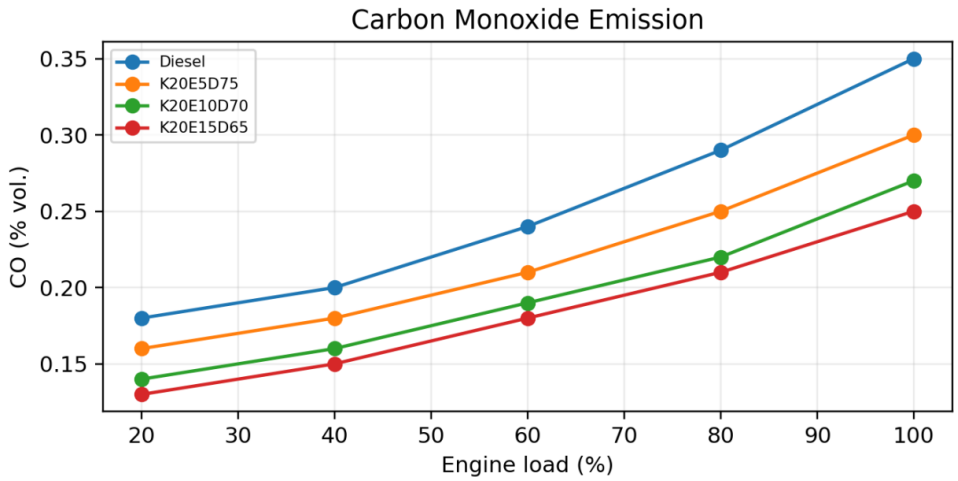

Figure 5. Representative CO emission.

6.2 Unburned Hydrocarbons

The representative HC results decrease for K20E5D75 and K20E10D70 relative to diesel. At still higher ethanol concentration, the reduction becomes smaller because charge cooling and poor ignition quality can increase quenching or partial burning. This illustrates why emission response should be determined experimentally rather than assumed from fuel oxygen content alone.

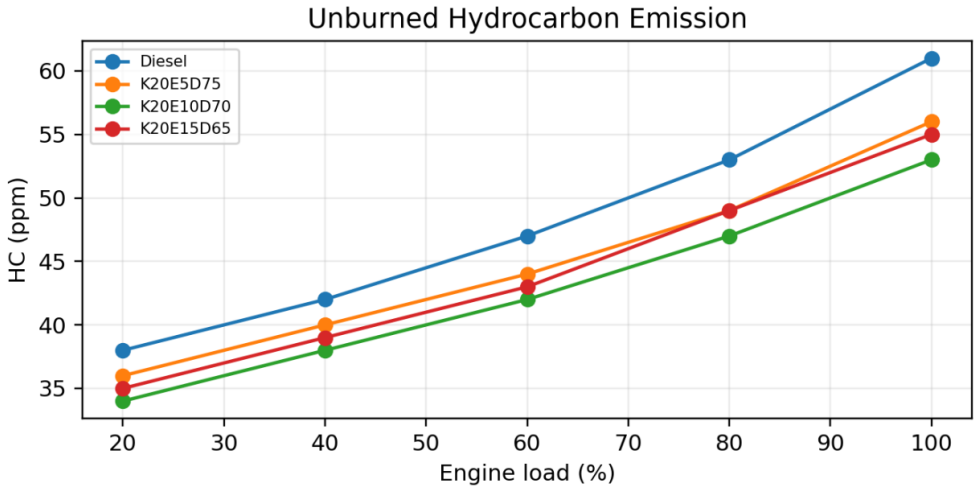

Figure 6. Representative HC emission.

6.3 Oxides of Nitrogen

NOx depends on local oxygen concentration, combustion temperature and residence time. Oxygenated blends can increase NOx if combustion becomes more complete and hotter, while ethanol charge cooling can decrease NOx. The representative K20E10D70 case gives a modest increase over diesel, but the literature contains both increases and decreases; injection timing, EGR and load are decisive.

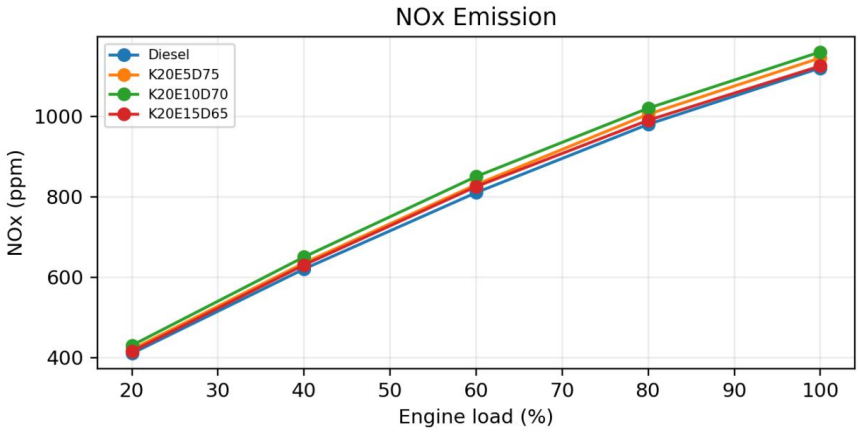

Figure 7. Representative NOx emission.

6.4 Smoke Opacity

Smoke reduction is one of the most consistent advantages of oxygenated ternary blends. Both ethanol and biodiesel reduce the local fuel-rich conditions that promote soot formation. In the representative full-load data, smoke falls from 62% for diesel to 49% for K20E10D70 and 46% for K20E15D65.

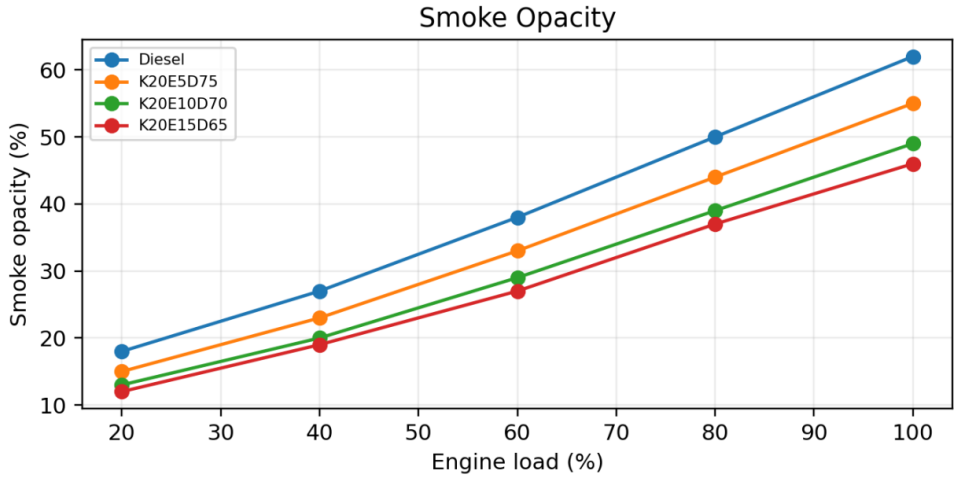

Figure 8. Representative smoke-opacity variation.

7. Comparative Assessment

Table 4. Representative full-load comparison.

Full-load parameter	Diesel	K20E5D75	K20E10D70	K20E15D65
BTE (%)	30.0	30.7	31.5	30.4
BSFC (kg/kWh)	0.28	0.29	0.30	0.32
EGT (°C)	430	420	412	402
CO (% vol.)	0.35	0.30	0.27	0.25
HC (ppm)	61	56	53	55
NOx (ppm)	1120	1145	1160	1125
Smoke opacity (%)	62	55	49	46

The combined comparison identifies K20E10D70 as the most balanced representative blend: it provides the highest BTE, moderate BSFC, reduced CO/HC/smoke and acceptable EGT, although NOx is slightly higher than diesel. K20E15D65 provides the lowest smoke and CO but incurs a larger BSFC penalty and may require ignition-quality or injection-timing optimization.

CONCLUSIONS

This paper develops an experimental methodology for evaluating ethanol–Karanja biodiesel–diesel ternary fuels in a CI engine. The literature supports Karanja biodiesel around 20% and ethanol up to approximately 10% as a technically relevant range for unmodified or lightly optimized diesel engines. In the representative dataset, K20E10D70 provides the best performance–emission compromise, with the highest BTE and substantial reductions in CO, HC and smoke. Increasing ethanol further to 15% reduces smoke and CO but increases BSFC and can intensify ignition-quality and blend-stability concerns. NOx remains strongly

condition dependent. The work confirms that ternary blends should be optimized jointly for fuel properties, combustion phasing, performance, gaseous emissions and particulate/smoke behavior.

Torque, speed, fuel flow, thermocouples, pressure sensors and gas analyzers must be calibrated before testing. Repeatability should be reported as standard deviation or confidence intervals. For a derived quantity R=f(x1,x2,…), combined uncertainty can be estimated by root-sum-square propagation of the sensitivity-weighted measurement uncertainties. Blend stability should be confirmed before and after testing, particularly for the 15% ethanol formulation.

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