Investigation into the performance and emission of diesel engine operating at different blends of Egusi melon (*Citrullus lanatus*) biodiesel

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ABSTRACT

The increasing global demand for sustainable energy has led to a rise in interest in biodiesel as an eco-friendly alternative to fossil fuels. This study investigates the performance and emission characteristics of a diesel engine powered by different blends of Egusi melon (*Citrullus lanatus*) biodiesel. The blends tested include B20, B50, B100, and pure diesel (B0). Performance metrics such as brake power and specific fuel consumption (SFC), as well as emissions of carbon monoxide (CO), unburned hydrocarbons (UHC), and nitrogen oxides (NOx), were analyzed. The results showed that increasing biodiesel content reduced CO and UHC emissions, with B100 showing the lowest CO emissions (0.01%) at 1600 rpm. However, NOx emissions increased slightly with higher biodiesel content. While engine power decreased marginally for higher biodiesel blends, Egusi melon biodiesel demonstrated significant environmental benefits and reasonable performance, highlighting its potential as a viable alternative diesel fuel.

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1. INTRODUCTION

Global energy consumption is still heavily reliant on fossil fuels such as petroleum, coal, and natural gas, which account for over 80% of global energy needs [1]. However, the finite nature of these resources, coupled with rising prices and environmental degradation, including greenhouse gas emissions and climate change, has spurred global efforts to explore renewable and cleaner alternatives. Biodiesel has emerged as a promising renewable substitute for fossil diesel due to its biodegradability, lower emissions, and compatibility with existing diesel engines. Biodiesel is typically produced through transesterification of vegetable oils or animal fats with alcohol, yielding fatty acid methyl esters (FAMEs) [2]. Extensive research has evaluated the properties, performance, and emission characteristics of biodiesel derived from both edible and non-edible feedstocks [3]–[7]. Several studies have highlighted the environmental benefits of biodiesel, such as reduced carbon monoxide (CO) and unburned hydrocarbon (UHC) emissions due to its inherent oxygen content [8]–[10]. However, biodiesel blends often result in higher nitrogen oxide (NOx) emissions, primarily due to elevated combustion temperatures [11]. The trade-off between emission benefits and NOx increase has led to research on additives, such as diethyl ether (DEE) and toluene, to mitigate NOx while maintaining performance [11]–[22]. While biodiesel from common feedstocks like palm, soy, and jatropha has been widely studied, lesser-known crops like Egusi melon (Citrullus lanatus) present untapped potential, particularly in regions like sub-Saharan Africa where Egusi is abundant but underutilized. Prior research has explored the physicochemical properties of Egusi oil, noting favorable viscosity, cetane number, and calorific value, aligning well with American Society for Testing and Materials (ASTM) biodiesel standards [2], [4]. Despite these promising properties, empirical data on the performance and emission characteristics of Egusi biodiesel in diesel engines remain limited. Understanding how Egusi biodiesel performs under varying engine speeds and blends is essential to assess its practical viability. This study aims to evaluate the performance and emission characteristics of a diesel engine operating on different blends (B20, B50, and B100) of Egusi melon biodiesel compared to conventional diesel (B0). Specifically, the research investigates the impact of these blends on key engine performance metrics such as brake power and specific fuel consumption (SFC), as well as exhaust emissions of CO, UHC, and NOx. The study contributes to expanding the database of non-traditional biodiesel feedstocks and supports the development of locally sourced, sustainable energy alternatives.

2. METHOD

2.1. Collection of seeds and oil extraction

The Egusi melon seeds used for this experiment were obtained from Ogige market, Nsukka, Enugu State. The seeds were dried and ground. The ground seeds were transported to the Department of Nutrition and Dietetics, University of Nigeria Nsukka laboratory for further processing. The oil extraction technique used was the Soxhlet extraction method using n-hexane. 700 ml of n-hexane was added to a conical flask containing the ground seeds. The mixture was then heated to 60 °C for several hours and stirred, after which it was filtered to separate the solvent-oil mixture from the seed residue. Finally, a rotary evaporator was used to evaporate the n-hexane in the solvent-oil mixture, leaving behind pure Egusi oil. The mass and volume of the extracted oil were recorded as 1.24 kg and 1.4 liters, respectively. The extracted oil was heated to 70 °C in a conical flask. A mixture of preheated concentrated sulfuric acid (H_2SO_4) and methanol was added to the oil and stirred for one hour. The mixture was left to settle for about two hours to allow the components to separate, thereby reducing the free fatty acid content of the oil.

2.2. Preparation of Egusi melon methyl ester (transesterification process)

Once bio-oil is extracted, it is converted to biodiesel (methyl ester) through transesterification. Transesterification is a process of reacting a bio-oil with alcohol in the presence of a catalyst. It converts triacyl-glycerides in the bio-oil to methyl ester, yielding glycerol as a byproduct.

For the transesterification process, 1.0 liter of the extracted Egusi oil was mixed with sodium methoxide solution, prepared by dissolving 5 grams of sodium hydroxide (NaOH) in 500 ml of methanol in a 2:1 ratio. The solution was mixed for 30 minutes at 50 °C using a magnetic stirrer to ensure complete dissolution of sodium hydroxide. After mixing, the solution was transferred into a separator funnel and allowed to separate for 24 hours. After 24 hours, the mixture separated into two layers: the top layer (biodiesel), which was light, and the bottom layer (glycerol) which was thicker and white. The biodiesel was separated and washed by adding 30 ml of distilled water and heating to 120 °C to remove any remaining water and glycerol. The final volume of biodiesel produced was 1.09 liters. The biodiesel was blended or mixed with pure diesel to obtain two different blends code-named B20 and B50.

For B20 (containing 20% biodiesel), 100 ml of biodiesel was mixed with 400 ml of pure diesel. For B50 (contains 50% biodiesel), 250 ml of biodiesel was mixed with 250 ml of pure diesel. The unblended biodiesel was coded B100 while the pure diesel was coded B0.

2.3. Measurement of properties

The physicochemical properties of biodiesel influence its fuel characteristics and performance in a diesel engine. For this experiment, the properties of the different fuel blends used were measured, which are shown in Table 1. In particular, the properties of the pure biodiesel codenamed B100 may be compared with the measured properties of Egusi melon oil methyl ester (biodiesel) obtained by previous authors [23], [24]. These properties are shown to confirm biodiesel ASTM standards.

2.4. Experimental setup

Two tests were carried out on the diesel and Egusi Melon biodiesel blends, namely, the diesel engine performance test and the emission test. The experiment took place at the University of Nigeria, Nsukka, Mechanical Engineering Laboratory. The test engine was a four-cylinder, naturally aspirated, water-cooled diesel engine with a direct injection system, capable of generating 112 kW (150 horsepower). The engine was securely mounted on a test bed, and its output shaft was connected to a hydraulic dynamometer. This dynamometer measured the engine's torque output using a dial indicator that displayed the force exerted by the engine's rotor. To simulate increased engine load, the dynamometer's wheel was rotated in a clockwise direction. The DC battery was connected, with functional valves remaining open during testing and adequate oil present in the engine. The air drum was properly positioned to draw air from the engine.

The engine was run at idle speed for 20 minutes to allow all components, including the engine block, cooling, and lubrication systems, to reach optimal operating temperatures. During testing, the engine was operated at a maximum load of 10 kN and maintained at a steady 1000 rpm using a tachometer and dynamometer. Torque output was recorded, and fuel consumption was measured by timing the consumption of 50 cm³ of fuel. The manometer and exhaust temperature were also recorded. The procedure was repeated at higher engine speeds (1300, 1600, 1900, and 2200 rpm), with engine torque kept constant at 10 Nm. Initial tests used pure diesel (B0) to establish baseline data, followed by tests with B100, B20, and B50. Before running the engine with a new test fuel, the fuel filters were changed, and the system was bled to ensure a complete transition from one test fuel to another and eliminate all traces of air from the system. Engine performance was evaluated using parameters such as fuel consumption rates, brake power, brake-specific fuel consumption (BSFC), volumetric efficiency, brake mean effective pressure, brake thermal efficiency (BTE), and air-fuel ratios. The emission characteristics from the exhaust were measured using the Bacharach PCA2-15068 model emission gas analyzer thong at the exhaust pipe end of the diesel engine. The emissions from the exhaust of the diesel engine were tested for CO, UHC, sulfur, and NOX. Each measurement was conducted at least twice to ensure accuracy.

Table 1. Physico-chemical properties of diesel and biodiesel blends

S/N	Parameters	B0	B100	B20	B50	ASTMD6751
1	Density (kg/m³)	835	886	845.2	860.4	860–900
2	Calorific value (J/g)	44,200	39,000	43,160	41,600	-
3	Cetane number	47	63	57	59	30–65
4	Iodine value (mgKOH/g)	-	45.07	41.8	44.3	42–46
5	Kinematic viscosity [40 °C] (mm²/s)	3.2	4.05	3.5	3.92	1.9–6
6	Flash point (°C)	-	144	127	136	100–170
7	Cloud point (°C)	-	10	4	6	-3–12
8	Saponification value (mgKOH/g)	-	161.02	160.02	160.58	-
9	Free fatty acid (%)	-	0.24	0.18	0.21	<0.26
10	Peroxide value (meq/kg)	-	1.88	1.63	1.84	-<0.8
11	Acid value (mgKOH/g)	-	0.49	0.39	0.43	

3. RESULTS AND DISCUSSION

3.1. Effect of engine speed on specific fuel consumption

The impact of engine SFC for the different fuel blends, which measures fuel efficiency in internal combustion engines, is illustrated in Figure 1. A lower SFC indicates better engine performance in terms of fuel economy. Figure 1 shows the SFC for pure diesel (B0), biodiesel (labeled as B100), and their blends (B20 and B50) as a function of engine speed.

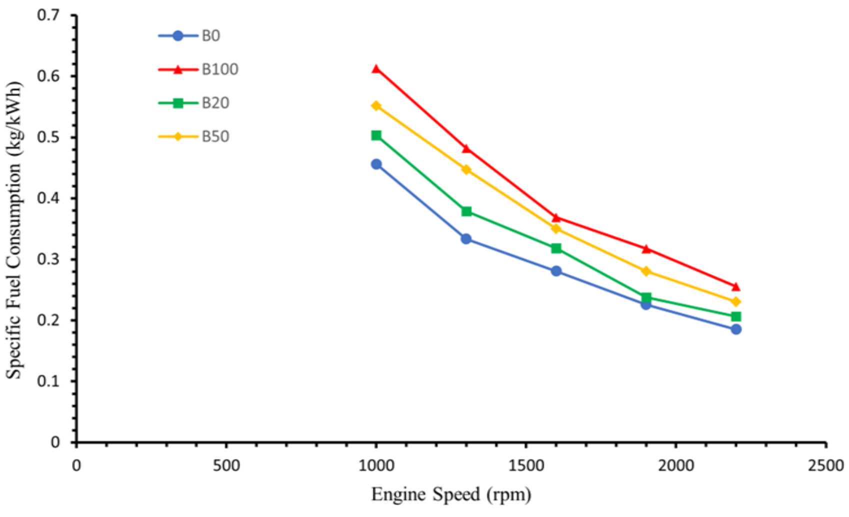

Figure 1. SFC of fuel blends at different engine speeds

It was observed that for both diesel and biodiesel blends tested, the SFC decreases with an increase in engine speed. As engine speed rises, the engine requires more power to sustain these higher speeds. The improvement in fuel efficiency, indicated by lower SFC values at elevated speeds, is likely due to the engine's ability to convert more of the fuel's energy into useful work, aided by better thermal management. At higher speeds, engines operate at greater loads, which allows for better thermal efficiency. Thus, they extract more energy from the fuel and convert it into useful work, resulting in a reduced fuel consumption rate. Additionally, the graph shows that across all engine speeds, the unblended biodiesel B100 consistently displays higher SFC values compared to the other fuels B50, B20, and B0. This indicates that as the ratio of biodiesel increases from B0 to B100, the SFC also increases. This phenomenon can be attributed to biodiesel's inherent properties, as it generally has lower energy density and higher viscosity compared to diesel fuel [25]. As a result, biodiesel requires more energy to ignite and burn efficiently, leading to increased fuel consumption and higher SFC values.

3.2. Effect of Engine speed on brake power

In an internal combustion engine, brake power refers to the usable power generated by the engine shaft. As illustrated in Figure 2, engine power increases with increasing speed for all the fuels. Notably, blends with lower biodiesel content exhibit slightly higher brake power.

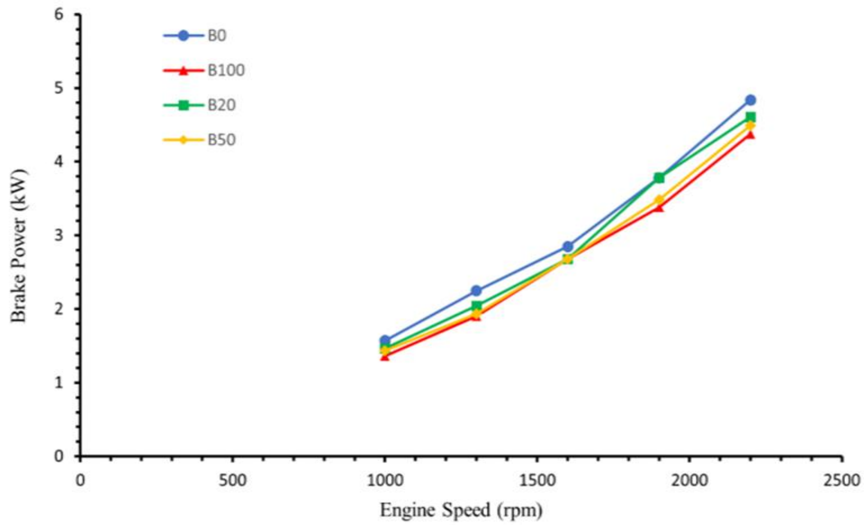

Figure 2. Graph of brake power

Pure diesel B0 shows the highest power at all speeds. However, the biodiesel blend B20 displays remarkable potential as it gives a power output that is comparable to the pure diesel B0, especially as the engine speed increases. Particularly at 1900 rpm, both B0 and B20 produce the same power of about 3.6 kW.

3.3. Carbon monoxide emission

The variation of CO emissions at different engine speeds for various fuel blends is illustrated in Figure 3. As engine speed increases, diesel emissions B0 worsen, reaching a CO level of 0.12% at the highest speed. In contrast, biodiesel blends such as B50 and B100 begin with zero CO emissions at lower speeds. However, as the speed increases, the biodiesel blends start producing some CO emissions. At 1600 rpm, for instance, B20 emits 0.02% CO, B50 0.018% CO, and B100 0.01% CO. It can be seen that the level of CO emissions decreases as the biodiesel content increases. This discrepancy can be attributed to the oxygen content in biodiesel, which facilitates more complete combustion, particularly under high engine loads. This explains why biodiesel and its blends emit less CO compared to pure diesel at higher speeds.

3.4. Unburned hydrocarbon emission

Figure 4 illustrates the correlation between engine speed and UHC emissions for the different fuel types. Diesel fuel produces the highest levels of UHC emissions, exceeding those generated by B100 and B50 blends by more than four times. The UHC emissions from B100, B50, and B20 fuels show similar trends across the engine speed range. However, at the highest speed setting, B20 exhibits a slight increase in UHC emissions compared to B100 and B50. This increase can be linked to the higher viscosity of the fuel at elevated loads, which is known to affect emission levels.

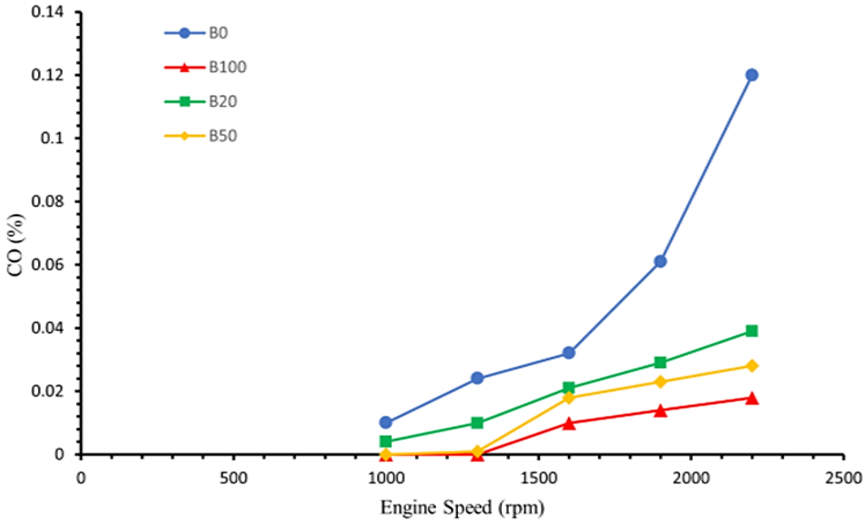

Figure 3. Variation of CO emissions with engine speed

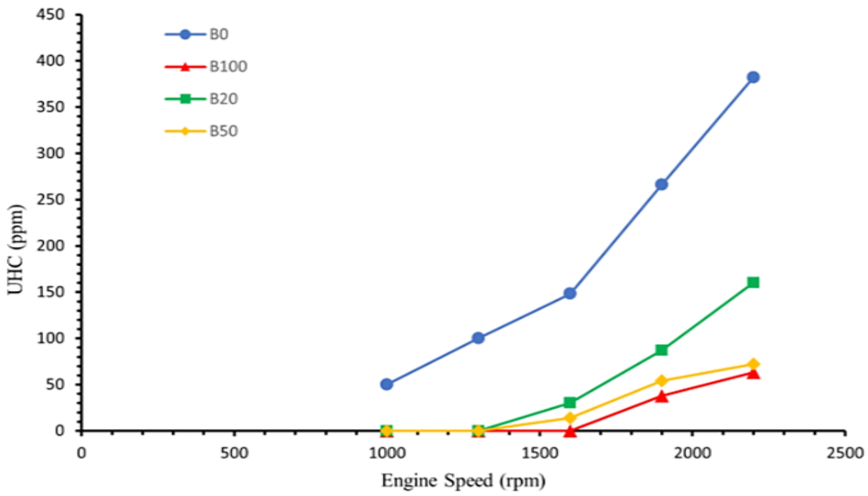

Figure 4. Variation of UHC with engine speed

Biodiesel blends demonstrate better performance regarding UHC emissions due to their higher oxygen content. This characteristic facilitates a more complete combustion process within the engine cylinder, resulting in reduced unburned hydrocarbons (UHC) in the exhaust. Additionally, biodiesel blends have increased viscosity, which improves fuel spray penetration and reduces wall-wetting issues in the cylinder. The combination of these factors leads to a more efficient combustion process, ultimately resulting in lower UHC emissions.

3.5. Nitrogen oxide emission

Figure 5 shows that as the engine speed increases, NOx emissions also rise. This correlation is well-established, as higher combustion temperatures often a result of using oxygenated fuels lead to greater formation of NOx. Thus, the presence of oxygenated biodiesel in blended fuels may explain the observed increase in NOx emissions.

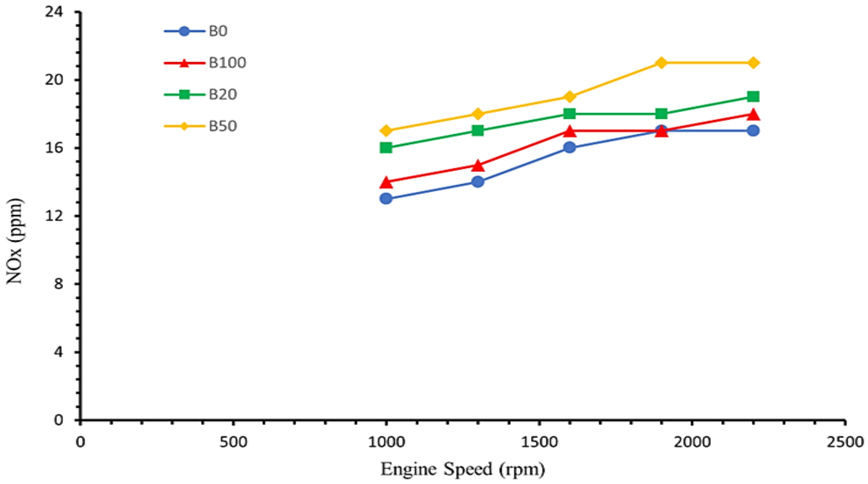

Figure 5. Variation of NOx with engine speed

3.6. Comparison between biodiesel and pure diesel

Table 2 reveals that SFC increases with higher biodiesel blends (B100 > B50 > B20) due to the lower energy density of biodiesel compared to pure diesel (B0), which requires more fuel to produce the same amount of power. Additionally, brake power experiences a decline with increasing biodiesel blends, reflected in more pronounced negative percentage changes, as the reduced calorific value of biodiesel lessens engine efficiency. This observation is consistent with findings that highlight reduced brake power in watermelon biodiesel [9] and diminished BTE in palm biodiesel blends [16].

Table 2. Percentage changes in engine performance and emissions for biodiesel blends (B100, B50, and B20) relative to (B0) at varying engine speeds (N)

N (rpm)		1000			1300			1600			1900			2200	
	B100	B50	B20	B100	B50	B20	B100	B50	B20	B100	B50	B20	B100	B50	B20
SFC	34.4	21.0	10.4	44.6	34.1	13.7	31.5	24.9	13.4	40.5	24.2	5.5	38.1	24.6	11.3
B_P	-13	-9	-7	-15	-14	-9	-6	-6	-6	-11	-8	0	-10	-7	-5
CO	-100	-100	-60	-100	-96	-58	-69	-44	-34	-77	-62	-52	-85	-77	-68
UHC	-100	-100	-100	-100	-100	-100	-100	-91	-80	-86	-80	-67	-84	-81	-58
NO_X	7.7	30.8	23.1	7.1	28.6	21.4	6.3	18.8	12.5	0	23.5	5.9	5.9	23.5	11.8

Negative values indicate reduction vs B0

Furthermore, both CO and UHC show a significant decrease with the use of biodiesel, indicated by negative values. The oxygen content in biodiesel facilitates more complete combustion, resulting in lower emissions of UHC and CO. This is supported by evidence that B30 biodiesel reduced CO emissions by 45.5% [8] and the assertion that oxygen present in biodiesel contributes to the reduction of CO levels [11]. On the other hand, NOx exhibit an increase, attributed to higher combustion temperatures and enhanced oxygen content in biodiesel that promote NOx formation. This aligns with observations that Karanja biodiesel increased NOx emissions by 10–13% [10] and that the inclusion of propanol additives can help mitigate NOx levels [22].

3.7. Trade-offs (fuel economy vs emissions)

Increasing the biodiesel content enhances combustion efficiency, resulting in a significant reduction of CO and UHC by up to 100% (Table 2). However, this improvement comes at the expense of higher SFC, potentially increasing by as much as 44.6% (Table 2) along with elevated Nox emissions, which may rise by up to 30.8% (Table 2). Additionally, there is a reduction in brake power of up to 15% when compared to pure diesel (B0).

In summary, while biodiesel blends (B100-B20) effectively lower CO and UHC emissions compared to conventional diesel, these benefits are accompanied by challenges such as increased fuel consumption, diminished engine power, and higher NOx emissions. Therefore, the widespread adoption of biodiesel necessitates a careful consideration of these trade-offs, particularly in terms of operating costs and strategies for mitigating NOx emissions.

4. CONCLUSION

This study demonstrates the potential of Egusi melon biodiesel as a viable and sustainable alternative to conventional diesel fuel. The fuel blends exhibited lower CO and UHC emissions, with B100 achieving the most significant reductions. Although there was a slight increase in NOx emissions and a marginal reduction in brake power, the trade-offs are acceptable within current environmental goals. Egusi biodiesel meets key fuel standards and can be produced from locally available resources, making it a promising candidate for renewable energy development in tropical regions. Further research should explore engine tuning, additive use (e.g., DEE, exhaust gas recirculation (EGR)), and long-term engine wear analysis to optimize its application.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [initials: PCO], upon reasonable request.

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