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Original Article

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'Comparative analysis of diesel fuel types on engine performance and emissions'

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Abstract

This study explains the exhaust and combustion features of four types of diesel fuel using a direct injection diesel engine having 4-strokes and 1-cylinder. The investigation focuses on the performance of brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), and gasses emissions like carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and smoke opacity. Results show that diesel fuels of Types 3 and 4 display superior performance with increasing brake productivity up to 20% and reducing smoke emissions associated to other fuel types up to 40% highlighting their potential for enhancing engine efficiency and reducing environmental impact. These results show that diesel fuel Type 3 enhanced combustion and emission profiles in diesel engines presenting a valuable avenue for engine optimization and environmental compliance.

Keywords: combustion; diesel engine; emission; environment; optimization

1 Introduction

Tracking down sustainable and efficient energy clarifications is an acute challenge in the field of technical sciences, above all within mechanical engineering [1]. In the surroundings of Baghdad, a city faced with major urbanization and industrialization, the goal for optimized fuel use in diesel engines is foremost [2]. This research, conducted at Mustansiriyah University, Department of Mechanical Engineering, with the assistance of the university's full library of resources, searches were conducted into the emission and combustion features of various diesel fuels produced by the top refineries in the region [3].

Diesel engines, due to their durability and fuel economy, are the main type of engine for moving people and goods in Baghdad [4]. The main fuel products such as diesel, liquefied petroleum gas (LPG), and petroleum are mostly produced using alternative fuels that have been obtained and supplied from leading refineries leading to significant participation on the side of local energy companies [5, 6]. However, it's important to understand that diesel engine emissions including hydrocarbons (HCs), nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter apart from CO_2, have a great impact on both the environment and also cost [7].

In Baghdad, the fuels that are used most of the time, notably benzine, diesel, and LPG, form the backbone of the city's energy consumption. This study will examine the performance and emission features of different diesel fuels, aiming at their potential to enhance engine efficiency and also reduce the emission of harmful gasses [8, 9]. By taking the expertise of Mustansiriyah University and the resources available within the Department of Mechanical Engineering, this study seeks to give valued insights into the optimization of diesel engine operations in urban settings for which four different samples of diesel fuel are sourced from different refineries. These types of diesel fuel could have differences in their chemical composition, production processes, or additives, which can disturb their combustion characteristics and emission profiles when used in a diesel engine [3, 10].

As Baghdad continues to develop, the adoption of improved diesel fuels will be a significant role in enhancing air quality and the health of every single living thing (not only humans), supporting the city's durable environmental and financial objectives [11].

While extensive research has been conducted on the performance and emission characteristics of diesel fuels, there is a significant gap in understanding how different diesel fuel types produced by local refineries in Baghdad specifically impact engine efficiency and emissions under the city's unique urban conditions. Existing studies often generalize findings without considering the distinct chemical compositions, production processes, and additives used in these fuels, which can markedly affect their combustion properties and emission profiles. This research aims to address this gap by conducting a detailed comparative analysis of diesel fuels sourced from Baghdad's top refineries, providing insights that are crucial for optimizing fuel use in this rapidly urbanizing environment [12].

2 Test engine and experimental procedure

2.1 Test engine specifications

These experiments were carried out using a direct injection diesel engine having 4-strokes and 1-cylinder. The specific details about the engine used in this study are summarized in Table 1.

This engine has been selected due to its ability to provide consistent and reliable performance outputs, making it ideal for comparative studies on fuel properties.

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Table 1. Specifications of the test engine

Parameters	Specifications
Engine type	Turbocharged diesel engine
Diesel mode	Yes
Dynamometer	Model XYZ Dyno
Fuel tank	Capacity: 60 liters
Temperature sensor	Thermocouple type
Emission control	Diesel particulate filter (DPF)
Torque	Maximum torque: 20 N.m at 1500 RPM
Horsepower	Maximum horsepower: 150 hp at 2000 RPM
Compression ratio	16:1
Cooling system	Liquid cooling system
Exhaust system	Exhaust gas recirculation (EGR) system

Table 2. Properties of test fuels

Property	Diesel Type 1	Diesel Type 2	Diesel Type 3	Diesel Type 4
Density (kg/m^3)	830	840	845	835
Viscosity (mm^2/s)	2.5	2.8	3.0	2.7
Flashpoint (°C)	60	62	64	61
Calorific value (MJ/kg)	42	43	44	42.5
Cetane number	48	50	52	49

Figure 1. Diesel engine test rig 4-strokes single-cylinder.

2.2 Fuel properties

Four different diesel fuels were sourced from refineries in different regions and samples were collected from refineries like Kirkuk Refinery, Haditha Refinery, Qayarah Refinery, and Siniya Refinery. The properties of these fuels have a broad effect on engine performance and emissions. The properties of the test fuels are listed in Table 2 [13].

2.3 Experimental setup

The setup for this experiment was designed to accurately measure the performance and emissions of the test engine using the various diesel fuels [14]. The setup comprised a test engine rig, a fuel supply system, and emission measurement instruments [15]. The engine was coupled to a dynamometer to measure performance characteristics such as BTE, BFSC, and EGT as shown in Fig. 1.

A key component of the setup was the use of a Testo 350 gas analyzer, a state-of-the-art device used for measuring emissions. The Testo 350 provided precise measurements of gasses like CO, HC, and NOx, and smoke opacity (while also being comfortable and portable) to handle as can be seen in Fig. 2 [16].

Figure 2. Testo 350 gas analyzer.

2.4 Experimental procedure

The experimental procedure planned to ensure the accuracy and reliability of the data and information collected. Initially, the test fuels were accurately prepared, and their properties were rigorously verified according to the specifications outlined in Table 2. Following this preparation phase, the engine was started and allowed to operate for a 15-minute period to stabilize its temperature, which is a critical step in establishing consistent initial conditions for all subsequent tests [17, 18]. To assess the environmental impact, advanced emission analyzers were used to quantify the levels of NOx, CO, HC, particulate matter, and CO_2 emitted by each fuel type. The collected data was subsequently analyzed using statistical methods to identify significant differences in performance and emissions among the fuel types, with additional

Table 3. Performance and emission parameters [12]

Parameter	Units	Measurement method
Brake thermal efficiency	%	Dynamometer and fuel flow
Brake specific fuel consumption	g/kWh	Dynamometer and fuel flow
Exhaust gas temperature	°C	Thermocouple
Carbon monoxide (CO)	% vol	Testo 350 gas analyzer
Hydrocarbons (HCs)	ppm	Testo 350 gas analyzer
Nitrogen oxides (NOx)	ppm	Testo 350 gas analyzer
Smoke opacity	%	Smoke meter

correlation studies conducted to determine the relationship between fuel composition and engine performance. To ensure accuracy and reliability, the results were validated through repeated testing and cross-referencing with existing studies. This methodology ensures that the findings of this study are robust and contribute valuable insights into optimizing diesel fuel use in Baghdad's urban environment.

Baseline measurements were then conducted using a reference diesel fuel to establish a performance and emissions benchmark. Then, each test fuel was systematically introduced into the test engine, which was maintained at a constant rotation of 1500 rpm throughout the testing phase with a compression ratio of 17:1. At the same time the different parameter outputs from the diesel engine are studied and recorded to pass it through analytical analysis for further conclusion [19].

The Testo 350 gas analyzer, as shown in Fig. 2, was used to measure the emission of harmful gasses from the test engine in order to determine which fuel type is most harmful to nature.

To ensure a thorough analysis, data collection was conducted at varying engine loads ranging from 0% to 100% of the engine's rated capacity under different conditions. This approach enabled a detailed examination of how the performance and emission features of each fuel varied under different operational conditions.

2.5 Data analysis

The performance metrics and emissions were analyzed using statistical tools, specifically Analysis of Variance (ANOVA), to statistically determine the differences in emission levels between the fuel types which is a powerful statistical method that allows for comparing the means of multiple groups to determine if there are any statistically significant differences among them, in order to determine the significance of variances observed between the fuels. Different methods were used and each parameter has a different unit which is detailed in Table 3.

By following this experimental method, the comprehensive insights into how different diesel fuels disturb engine performance and emissions guide the selection of optimal fuels for reducing the environmental impact and improving efficiency in urban settings like Baghdad which are explained in detail in the below section.

3 Results and discussion

Focusing on the performance metrics and emission features of the diesel engine when fueled with different diesel types, the data obtained shows the following results.

3.1 Brake thermal efficiency (BTE)

The brake thermal efficiency (BTE) of the engine was evaluated using four different diesel fuels at different torque levels which in this case ranged from 0–20 N.m. As can be seen in Fig. 3, diesel Type 3 consistently performed better than the other fuels in terms of BTE across all torque levels.

At 0 N.m, all fuels recorded a BTE of 0%, indicative of the initial stage with no load. However, as the torque increased, significant differences in BTE were detected. Diesel Type 1 showed a regular increase in BTE, reaching a maximum of 16% at 20 N.m. Diesel Type 2 showed slightly better performance with a maximum BTE of 17% at the highest torque level. Diesel Type 3 established the highest BTE, reaching 20% at 20 N.m, recognized by its higher calorific value and cetane number, which improve combustion efficiency. Diesel Type 4 followed a similar trend to diesel Type 1 at a maximum BTE of 16% at 20 N.m. These results highlight that diesel fuel Type 3 is the most efficient in converting fuel energy into mechanical work, mainly at higher loads, which is crucial for reducing fuel consumption and operational costs in urban settings like Baghdad.

3.2 Brake specific fuel consumption (BSFC)

The brake specific fuel consumption (BSFC) capacity of the engine was also measured for the different diesel fuels at different loads. Fig. 4 indicates that diesel Type 3, exhibiting the highest BTE, demonstrated a reasonable BSFC, particularly at higher torque levels.

Diesel Type 1 recorded a BSFC of 1.17 kg/kWh at initial stage, decreasing to 0.49 kg/kWh at higher loads. Diesel Type 2, on the other hand, had a slightly higher BSFC of 1.2 kg/kWh at lower torque, reducing to 0.50 kg/kWh at higher loads. Diesel Type 3 showed a BSFC of 1.25 kg/kWh at lower torque, decreasing to 0.51 kg/kWh at higher loads, indicating its efficiency in fuel utilization despite its higher energy output. Diesel Type 4 displayed a BSFC similar to diesel Type 1, starting at 1.15 kg/kWh and reducing to 0.495 kg/kWh at higher loads. These findings emphasize the potential of diesel Type 3 as a more efficient fuel choice, as it effectively balances high energy transformation with lower fuel consumption, thus optimizing both performance and cost-efficiency.

3.3 Exhaust gas temperature (EGT)

Meanwhile, the exhaust gas temperature (EGT) was taken for all diesel fuels at various loads with the purpose of studying the ignition process and thermal conversion efficiency. In operation at 0 N.m and 200°C, and at 20 N.m and 600°C as shown in Fig. 5, the EGT figures of diesel Type 1 increased with a general inclination that relates with load variation as discussed below.

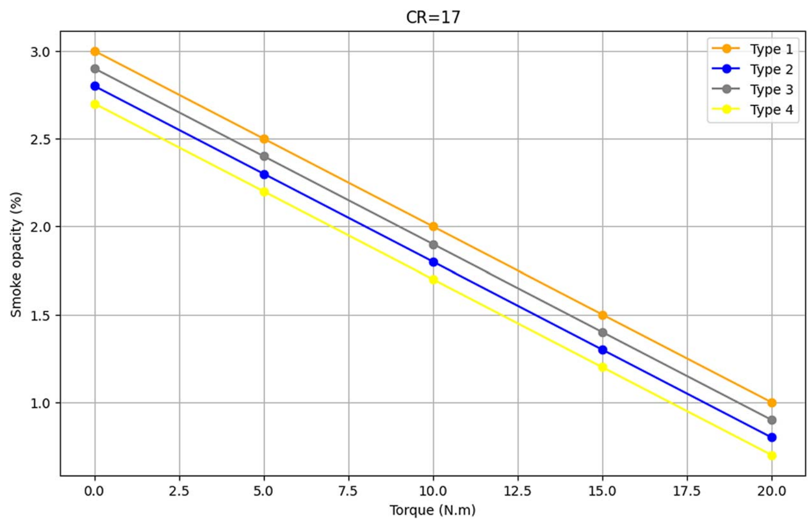

Figure 3. Brake thermal efficiency with different loads.

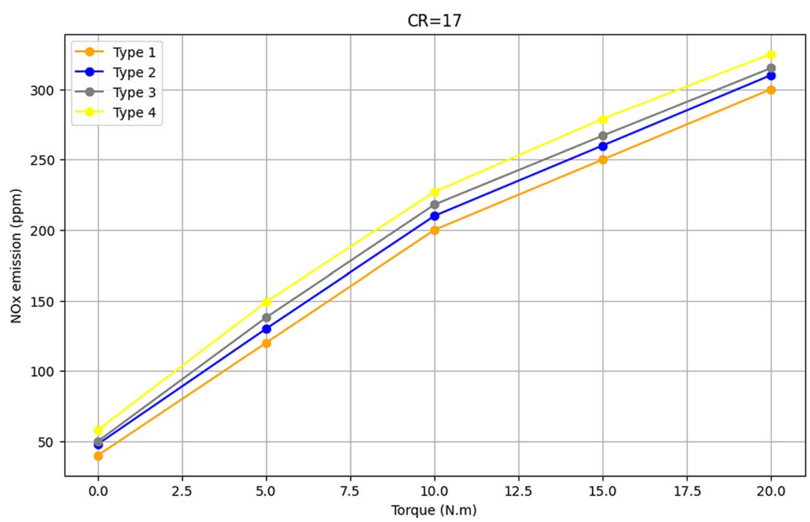

Figure 4. Brake specific fuel consumption at different loads.

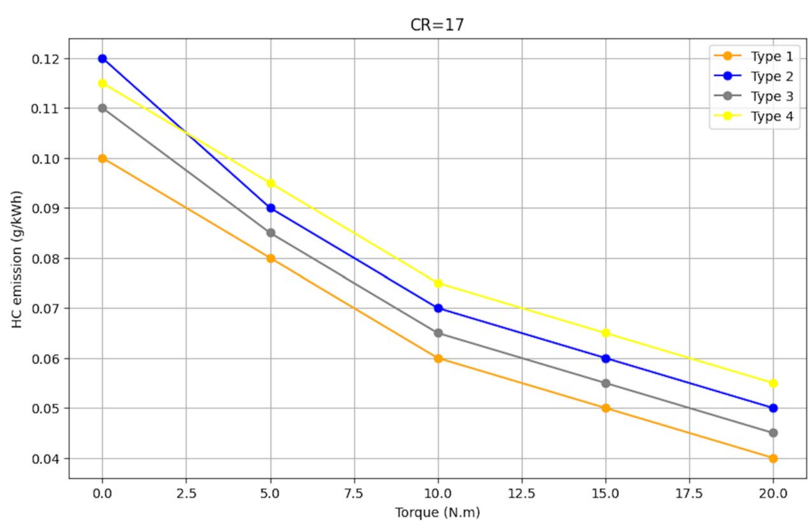

Figure 5. Changes in exhaust gas temperature with different loads.

Diesel Type 2 showed a comparable trend with EGT values increasing from 210°C to 610°C. Diesel Type 3 exhibited a slightly lower EGT range, from 205°C to 605°C, suggesting a more controlled combustion process. Diesel Type 4 recorded the highest EGT, ranging from 215° C at lower loads to 615°C at higher loads. Higher EGT values are generally

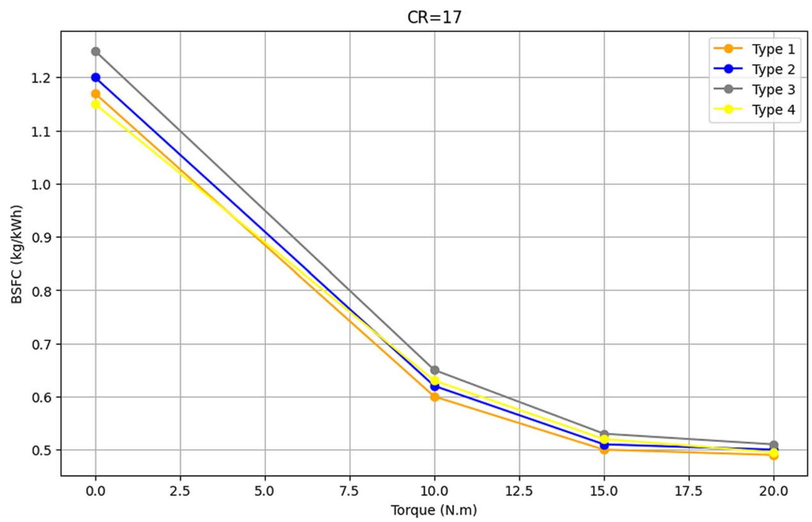

Figure 6. Emission of carbon monoxide with different loads.

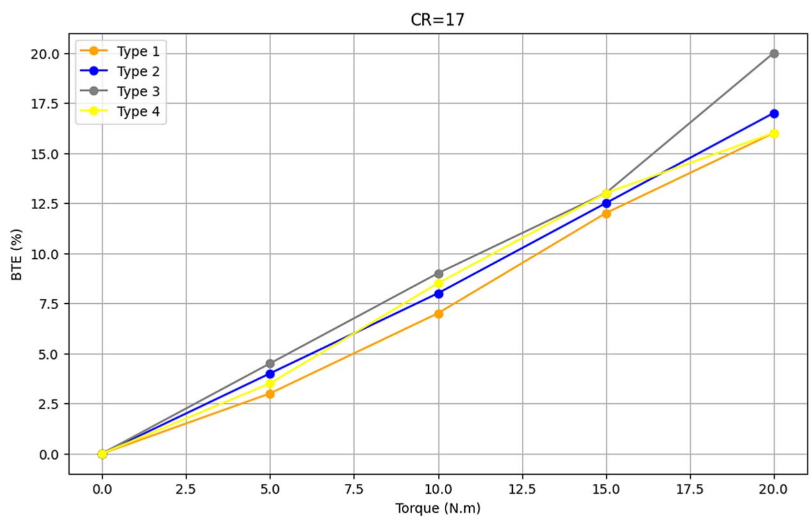

Figure 7. Emission of hydrocarbons with different loads.

indicative of better combustion efficiency but can also lead to increased NOx emissions. The EGT analysis suggests that diesel Type 4 has the highest thermal efficiency, diesel Type 3 provides a balanced performance with effective combustion and controlled thermal conditions, making it a suitable choice for optimizing engine performance and managing emissions.

3.4 Emission characteristics

The emission characteristics, including CO, HC, NOx, and smoke opacity, were critically evaluated for each diesel fuel to assess their environmental impact as shown in Figs 6, 7, 8, and 9. Diesel Type 3 consistently produced the lowest CO emissions across all loads, indicating more complete combustion. Similarly, HC emissions were lowest for diesel Type 3, reflecting its efficient fuel utilization. NOx emissions were higher for diesel Type 3 due to its higher combustion temperatures, which is a common trade-off for achieving higher thermal efficiency. The results show that diesel Type 1 and Type 4 gave moderate emissions of CO and HC when compared with diesel Type 2 which gave the highest emissions since fuel consumption in this category was low. In the case of smoke opacity, the indication that diesel Type 3 released lower particulate material in comparison to all the competition was obtained, and this fact suggested that the processes that have been enhancing combustion for this type of engine are purer. Diesel Types 1 and 4 had moderate smoke opacity levels, while diesel Type 2 showed the highest, reinforcing its lower combustion efficiency.

Diesel Type 3 demonstrated the best overall performance in terms of BTE, BSFC, and emissions, making it a suitable choice for enhancing engine efficiency and reducing environmental impact. While diesel Type 3 exhibited higher NOx emissions, this can be managed with appropriate after-treatment technologies. These findings offer valuable insights for optimizing fuel collection in urban environments like Baghdad, aiming to stabilize performance, efficiency, and environmental sustainability.

4 Conclusions

The performance and emission features of a single-cylinder, 4-stroke, direct-injection diesel engine powered with four different diesel types were widely studied. The key findings from this investigation are summarized as follows:

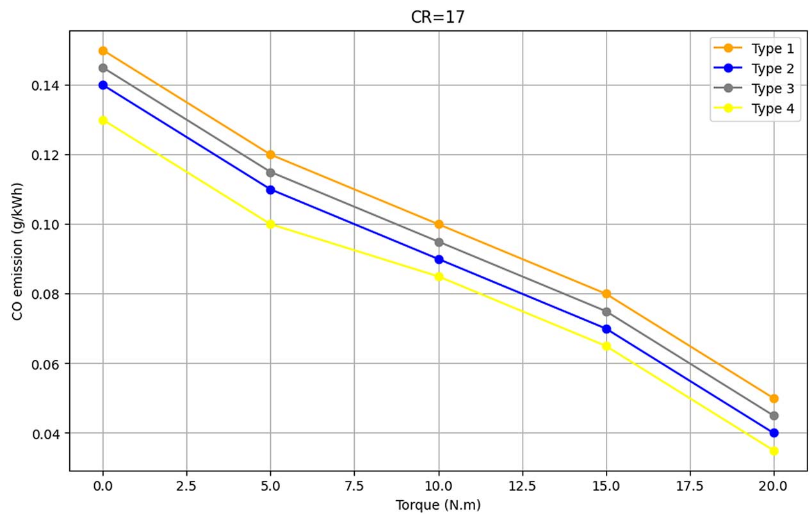

Figure 8. Emission of nitrogen oxides with different loads.

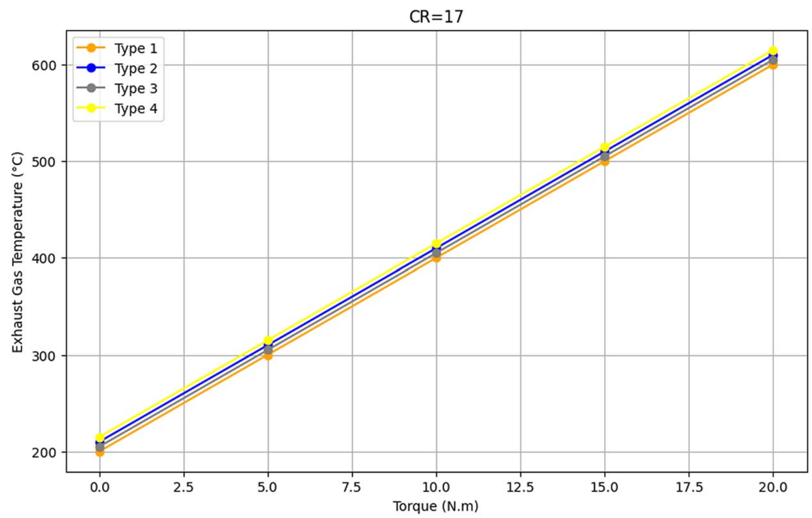

Figure 9. Smoke opacity variation with different loads.

- At the engine's maximum brake power, diesel Type 3 demonstrated the highest brake thermal efficiency (BTE) of 20%, outperforming other diesel types.
- Diesel Type 3 showed the lowest brake specific fuel consumption (BSFC) at higher loads, showing superior fuel efficiency when likened to the other diesel types.
- Diesel Type 3 showed controlled exhaust gas temperature (EGT), with lower values when related to other fuels, proposing a more efficient combustion process.
- CO emissions across all load have different outcomes but the case for Type 3 outperformed as it emits the lowest level.
- The lowest HC emissions are from diesel Type 3, reflecting its efficient fuel utilization and cleaner combustion process.
- Diesel Type 3 also had a high emission of nitrogen oxides (NOx) which is due to an increase in the combustion of the process.
- Diesel Type 3 confirmed the lowest smoke opacity, showing minimal particulate emissions and also cleaner emissions.
- Diesel Types 3 and 4 have better results than other fuel types in terms of both performance metrics and emission features, making them more appropriate for urban settings like Baghdad.

5 Future recommendation

Diesel Type 3 emerged as the best-performing fuel, demonstrating optimal performance with a relatively lower environmental impact. Based on these findings, it is recommended that efforts be made to enhance the efficiency and environmental performance of other diesel fuel types to match the standards set by diesel Type 3. This could involve refining the production processes, adjusting the chemical compositions, or incorporating similar additives that contribute to the superior characteristics observed in diesel Type 3.

Author contributions

Mohammed Qays Kadhim (Data curation, Formal analysis, Investigation [equal], Methodology, Resources, Software, Writing—original draft) and Petr Oshchepkov (Investigation [equal], Project administration, Supervision, Writing—review & editing).

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