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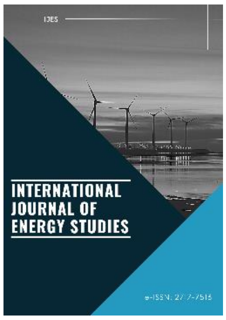

Research Article

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Performance and thrust analysis of J4/Biodiesel mixtures at different ratios in a high bypass ratio gas turbine engine

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Highlights

- The combustion performance of JP4 fuel was investigated in the Gasturb program.
- Thrust and performance analysis was carried out in cases of different biodiesel fuel additions.
- It has been found that the addition of biodiesel increases gross thrust.
- It has been determined that the addition of biodiesel reduces exergy and total pressure loss.

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ABSTRACT

Nowadays, when the aviation sector is of primary importance for both civilian and military purposes, efforts to improve the power generation mechanisms required for aircraft are of current importance. Researchers are working to make gas turbine engines operate more efficiently, cost-effectively and environmentally friendly. In this study, the performance values of a high bypass ratio gas turbine engine at different biofuel addition rates were numerically analyzed. In the study where JP4 was used as jet fuel, a mixture of 25% Triglyceride ($C_6H_8O_6$) and 75% Methanol ($C_1H_4O_1$) was used as biofuel. In the study, the biofuel ratio was increased by 10% molar intervals. The results showed that as the biofuel ratio increased, the total pressure and exergy at the core nozzle exit of the turbofan engine increased parabolically. In addition, the increased engine performance data was reflected in the thrust produced and the net thrust increased as a result of the biofuel addition.

Keywords: Gas turbine engine, Biofuel, Thrust

1. INTRODUCTION

Power plant systems are the most basic system used both for energy production and for vehicles to generate thrust. The two basic systems used for this purpose are piston engines and gas turbine engines. Although the piston engine is mostly used in land vehicles, it can also be used in combination with a propeller in aircraft. On the other hand, gas turbine engines have a greater usage area for aircraft in terms of applications requiring high thrust. In the literature, performance studies for different sections of gas turbine engines are frequently encountered. In these studies, both geometries and designs are changed. If necessary, different fuel types can be used. Studies examining the effects of different fuel types on combustion and engine performance have an important place in the literature. Taştan and Mızrak [1] tested the propane flame at different equivalence ratios in a premixed gas turbine burner. The study results showed that the optimum CO_2 emission level occurred at an equivalence ratio of 0.8. Kumuk and Ilbas [2] numerically analyzed Ammonia-Hydrogen combustion at high eddy ratios. The study results showed that the addition of ammonia increased NO_X emissions in the flame zone. However, when the swirl angle was 45°, a more homogeneous temperature distribution occurred in the combustion chamber. Chen et al., [3] investigated the effect of N_2 dilution on Ammonia Jet combustion in a non-premixed coflowed combustion chamber. The results show that increasing the inlet air temperature reduces NO_X emissions. It also shows that high air inlet temperature combinations reduce NO_X emissions of ammonia combustion.

Li et al. [4] examined the combustion and emission behavior in a staged gas turbine engine. The results show that increasing the inlet air temperature increases efficiency. However, with the increase in temperature, NO_X emissions also increased. Zhao et al. [5] numerically and experimentally tested the cavity-swirled combustion strategy for advanced gas turbine engines. The results show that air injection significantly affects combustion performance. It has been observed that the combustion chamber exit temperature is more homogeneous when the air injection hole is designed in the cavity outer-wall region. Additionally, in this case, high combustion efficiency was determined at high equivalence ratios. Özbek and Karyeyen [6] investigated the effect of different oxygen rates on the combustion characteristics in a scramjet engine. In this study, the oxygen content in the combustion air was massively reduced. The results showed that the speed increases as the oxygen content increased. In addition, as the flame position moved away from the burner, the temperature difference caused by the oxygen content decreased.

In studies carried out in the literature, the effect of biofuel additions on combustion performance and emission behavior is examined as a current issue. In these studies, different topics are studied such as engine performance and combustion chamber efficiency. Kumar et al., [7] investigated the combustion characteristics of Acetone-Ethanol-Butanol and Jet A1 mixtures. The results show up to a 30% reduction in pollutant emissions when Jet A1 fuel is blended with alternative alcohol-based alternative fuels. Alabaş and Çeper [8] analyzed kerosene-biogas mixtures for oxygen-enriched combustion. The results showed that CO and CO_2 emissions at the combustion chamber exit decreases with the addition of biogas. In addition, flame temperature values decreased and NO_X emissions decreased.

JP-4 fuel is a compound derived from a mixture of kerosene and benzine, produced by a special process to limit the Reid vapor pressure to between 2 and 3 psi to prevent vapor lock. Within the scope of the research program, studies have been focused on JP-4 fuel, with the assumption that biofuel production and JP-4 fuel will provide a more harmonious integration. In addition, the widespread availability of JP-4 fuel due to the fact that it consists of a kerosene/gasoline mixture aims to transform the theory into practical application in the following stages.

When the studies are summarized, it can be seen that the effect of different fuel types on the performance and emission data of gas turbine combustion chambers is currently examined and is an important field of study. Rather than analyzing all performance values of the engine, studies often focus on combustion chamber temperature and combustion chamber exit emission values. In recent years, the Gasturb program has started to be used to analyze the gas turbine engine with its air intake, compressor, combustion chamber and turbine components. Studies conducted in this program are published in high-impact journals and provide the opportunity for numerical analysis [9,10]. Unlike experimental combustion studies, this program allows for the calculation of exergy loss and analysis of impulse and total specific fuel consumption. In this study, for the first time in the literature, the effect of adding different amounts of biofuel to JP4 fuel on engine performance was investigated using the Gasturb program. Liquid biofuels and their properties were not taken from the program library but were created by the authors according to their chemical ratios. This study will contribute to research on the performance of biofuels in gas turbine engines, which is important in the field of sustainable aviation. Thus, the ratios of biogas addition to the thrust force, exergy and total pressure losses of the jet engine were determined.

2. METHODOLOGY

In this study, GasTurb 14 program was used to perform numerical analysis. GasTurb 14 is a simple and effective analysis software program designed to evaluate gas turbine performance and support preliminary design processes. This software is distinguished by a task-oriented graphical interface and high-quality graphical outputs. GasTurb 14 is designed for use in the gas turbine industry, aviation industry, airframe manufacturing, airline industry, aircraft engine maintenance, power generation industry and other operations of gas turbines used in air, land and sea. In addition to GasTurb 14, the GasTurb 6 module was used to create biofuel with reaction stages. Fuels were entered into the program manually according to the mixture ratios in the literature. Table 1 shows the chemical formulas of the components that make up JP4 fuel and their molar weights in the mixture [11].

Table 1. Composition of the JP4 fuel

The chemical formulas of the components that make up JP4 fuel and their molar weights in the mixture				
Reactant Name	**Molecular formula**	**Molecular Weight**	**Mole Fraction**	**Mass Fraction**
n-butane	C_4H_{10}	58.122	0,2	0,115668
n-pentane	C_5H_{12}	72,1488	0,015	0,0107686
n-hexane	C_6H_{14}	86,1754	0,06	0,0514488
n-heptane	C_7H_{16}	100,202	0,0822	0,0819575
isooctane	C_8H_{18}	114,229	0,3592	0,408275
isononane	C_9H_{20}	128,257	0,046	0,0587056
decane	$C_{10}H_{22}$	142,284	0,0152	0,0215199
undecane	$C_{11}H_{24}$	156,311	0,0148	0,0230192
cyclohexane	C_6H_{12}	84,1595	0,0285	0,0238665
1-heptene	C_7H_{14}	98,1861	0,0384	0,0375165
1-octane	C_8H_{16}	112,213	0,012	0,0133988
nonene	C_9H_{18}	126,241	0,0199	0,0249974
toluene	C_7H_8	92,1384	0,0144	0,0132021
ethylbenz	C_8H_{10}	106,165	0,025	0,0264096
mesitylene	C_9H_{12}	120,194	0,03	0,0358793
butylbenzene	$C_{10}H_{14}$	134,221	0,03	0,0400665
methylnapthalene	$C_{11}H_{10}$	142,2	0,0094	0,0133005

In the later stages of the study, molar biofuel was added to the list shown in Table 1 in order to change the fuel ratio in the mixture. In this study, a molar mixture of 25% Triglyceride ($C_6H_8O_6$) and 75% Methanol ($C_1H_4O_1$) was used as biofuel. The reason for using this fuel is its ease of availability and low cost [12]. Additionally, JP4 fuel has a lower C/H ratio compared to the hydrocarbons in the mixture. Table 2 covers the initial conditions and pressure values required for the numerical analysis, the general parameters and dimensional characteristics of the high-bypass turbofan engine as applied in the operating context. These parameters constitute the key performance indicators of the engine, which are indispensable for the examination of the pressurized and extended components of the engine, including the fan, compressor and turbine, in accordance with the specified analytical framework. Gas turbine engines used industrially perform combustion at a high air excess rate. The fuel-air ratio of the fuels used in the study was determined as 50, and lean combustion conditions were achieved with a high amount of air intake [13]. In addition, lower calorific value of biofuel added into JP4 is much lower than lower calorific value of JP4. While the lower calorific value of JP4 fuel is 44526 kJ/kg, the lower calorific value of 100% Biofuel mixture is 21876 kJ/kg. Furthermore, the data in this study were obtained for a Mach number of 0.8 and an altitude of 10,000 meters. First, the analysis was performed for pure JP4 fuel, and then the biofuel ratio was increased by 10% molar.

Table 2. Initial conditions

DESIGN PARAMETERS	
Parameter Name	**Parameter Value**
Suction Pressure Ratio	0,99
Internal Fan Pressure Rate	2,5
Outdoor Fan Pressure Rate	1,8
Compressor Internal Channel Pressure Rate	0,99
HP Compressor Pressure Rating	7
HP Compressor Pressure Rating	0,98
Bypass Rate	6
Combustion Chamber Exit Temperature	1450
Combustion Chamber Load Constant	1,6
Strength	50 kW
HP Reel Load Constant	0,99
LP reel Load Constant	1

Combustion Chamber Pressure Rate	0,97
Turbine Outlet Channel Pressure Ratio	0,98
ALTITUDE PARAMETERS	
Height	10000 m
Mach	0,8
Temperature	288,15 K
Pressure	101,325 kPa
FLUID PARAMETERS	
Air Density	1,225 kg/m^3
HPC Airflow	105 kg/s

A literature review was conducted for the biofuel planned to be tested for this study. The biofuels used stand out as alcohols that can be produced from biomass, biodiesel that can be produced from animal, vegetable and waste oils, and synthetic fuels such as Fischer-Tropsch (FT). The biofuel to be tested is obtained by the production method called transesterification. This method is the reaction of triglycerides with alcohols through renewable or non-renewable vegetable or animal oils.

$$C_6H_8O_6 + 3\,CH_4O \rightarrow RCO_2CH + C_3H_8O_3$$

The fuel that we obtain as a result of this reaction is not available in the GasTurb 6 program. The fuel we obtain as a result of this reaction is not available in the GasTurb 6 program. Therefore, for the creation of a new fuel file;

1) First, the "New Fuel" tab of the "Fuel" tab in the GasTurb 6 program interface should be opened. In the newly opened interface, first a name must be entered for the fuel you want to create.
2) Then, the reactants of the reaction required to create the fuel must be entered into the program as name, chemical formula and mole fraction.
3) After this information is entered, the “Path to FCEA2.exe” and “Path to Gasturb” options must be selected separately.
4) With the “Create temperature rise input” option on this screen, temperature rise data is obtained with the .inp extension. This data is run in the FCEA2 program.

5) Then, "Create CEA gas property input" should be selected in the GasTurb 6 program and the resulting data should be run again in the FCEA2 program.

6) In the last step, the "Make GasTurb file" option is selected to obtain a new fuel file with .gtb extension.

The reaction steps presented should be followed. Additionally, the reaction steps are schematized in Figure 1 for a better understanding of these steps.

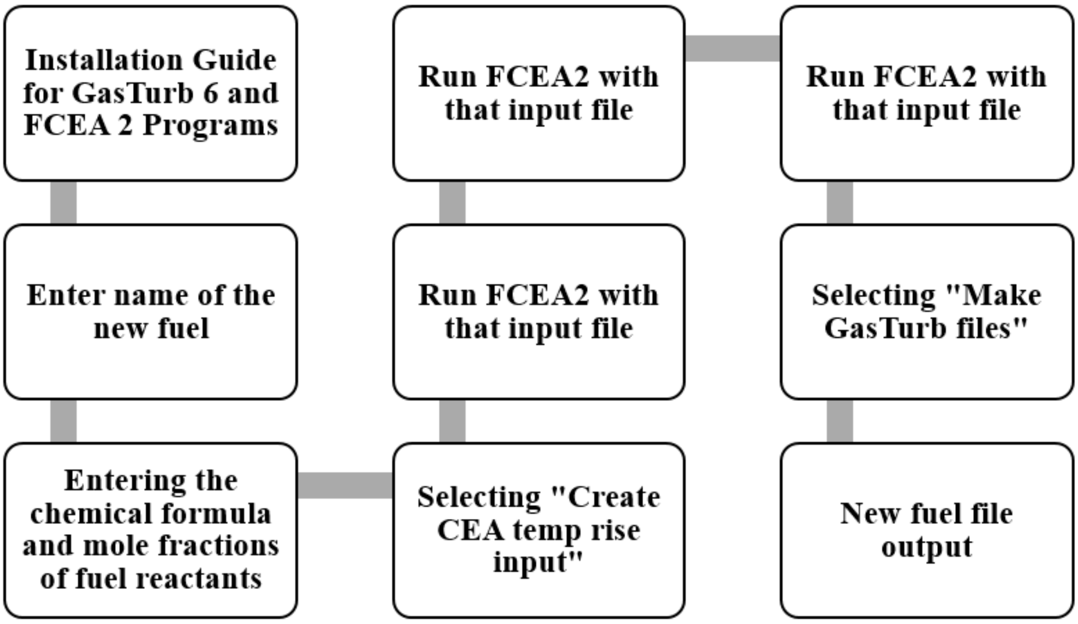

Figure 1. Reaction Steps

3. RESULTS AND DISCUSSION

The main task of a gas turbine engine with a high bypass ratio is to produce high thrust. For this purpose, the effect of different biofuel additives on the thrust performance of the engine was analyzed. The obtained data are presented in Figure 2. When the data is examined, it is seen that as the biofuel addition rate increases, the total thrust value of the engine increases. The increase is relatively modest at lower addition rates. However, as we approach 100% Biofuel ratio, the increase in thrust increases parabolically. The thrust value, which is 103.6 kN when 100% JP4 fuel is used, increases to 108.3 kN with 100% Biofuel. A total increase of 4.5% in thrust value was observed. This increase can initially be thought to be due to the increase in the mass of fuel entering the combustion chamber. While the air flow rate entering the core region of the engine was constant 105 kg/s, the fuel flow rate increased from 1.87 kg/s to 3.92 kg/s. However, the total amount of fuel and air expelled from the nozzle increased by 1.9%. In other words, a higher increase rate in thrust indicates that the engine operates more efficiently. In order to understand the exact reason for the increase in thrust, it is necessary to examine the Low Pressure Turbine outlet temperatures and also analyse the exergy and total pressure values.

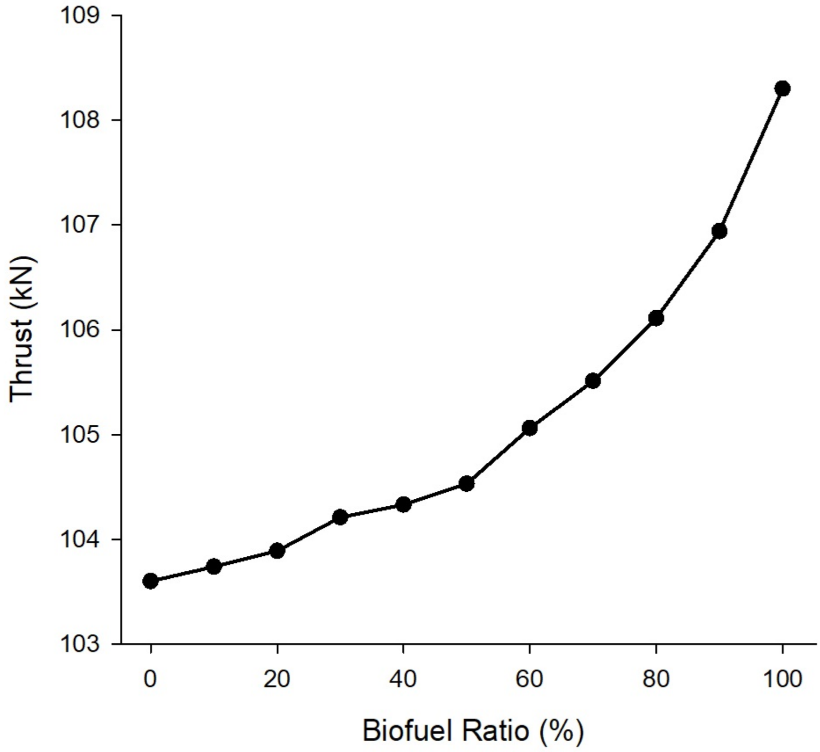

Figure 2. Effect of biofuel addition on thrust change

Figure 3 shows the change of three different data depending on each other with the addition of biofuel. The first one is the low pressure compressor (LPT) outlet temperature in Figure 3.a. The burnt gases coming out of this compressor are directed directly to the nozzle, expand and are discharged into the atmosphere. Gases coming out of the low pressure turbine with high energy can reach a higher nozzle exit speed and thus produce higher thrust. As can be seen in the study, as the biofuel addition is increased, the low pressure turbine outlet temperature increases. This situation supports the increase in net thrust. In addition, the other two most striking results are the total pressure and exergy values at the nozzle exit of the core part of the engine. In all industrial systems, in accordance with the principle of increase in entropy, there is an increase in entropy and therefore total pressure loss. Like other power generation mechanisms, minimum exergy and total pressure loss are demanding issues in terms of efficiency in gas turbine engines [14]. As can be seen in Figure 3.a-b in this study, exergy and total pressure values at the engine exit increased parabolically. This indicates that the use of biofuel results in lower irreversibility. Balli et al. [15] stated in their study that the addition of biofuel to jet fuel increased the rate of energy loss and resulted in lower exergy destruction. Similarly, in this study, it was determined that the use of biofuel increased the net thrust of the J69 engine. Studies in the literature show high irreversibility and flame temperature as the main reasons for high exergy destruction [16]. The lower calorific value of the biojet fuel used in this study contributes to lower exergy destruction and higher exergy gain. As it is known from the literature, fuels with low lower calorific value have lower adiabatic flame temperature. A lower adiabatic flame temperature leads to reduced exergy and total pressure loss.[17].

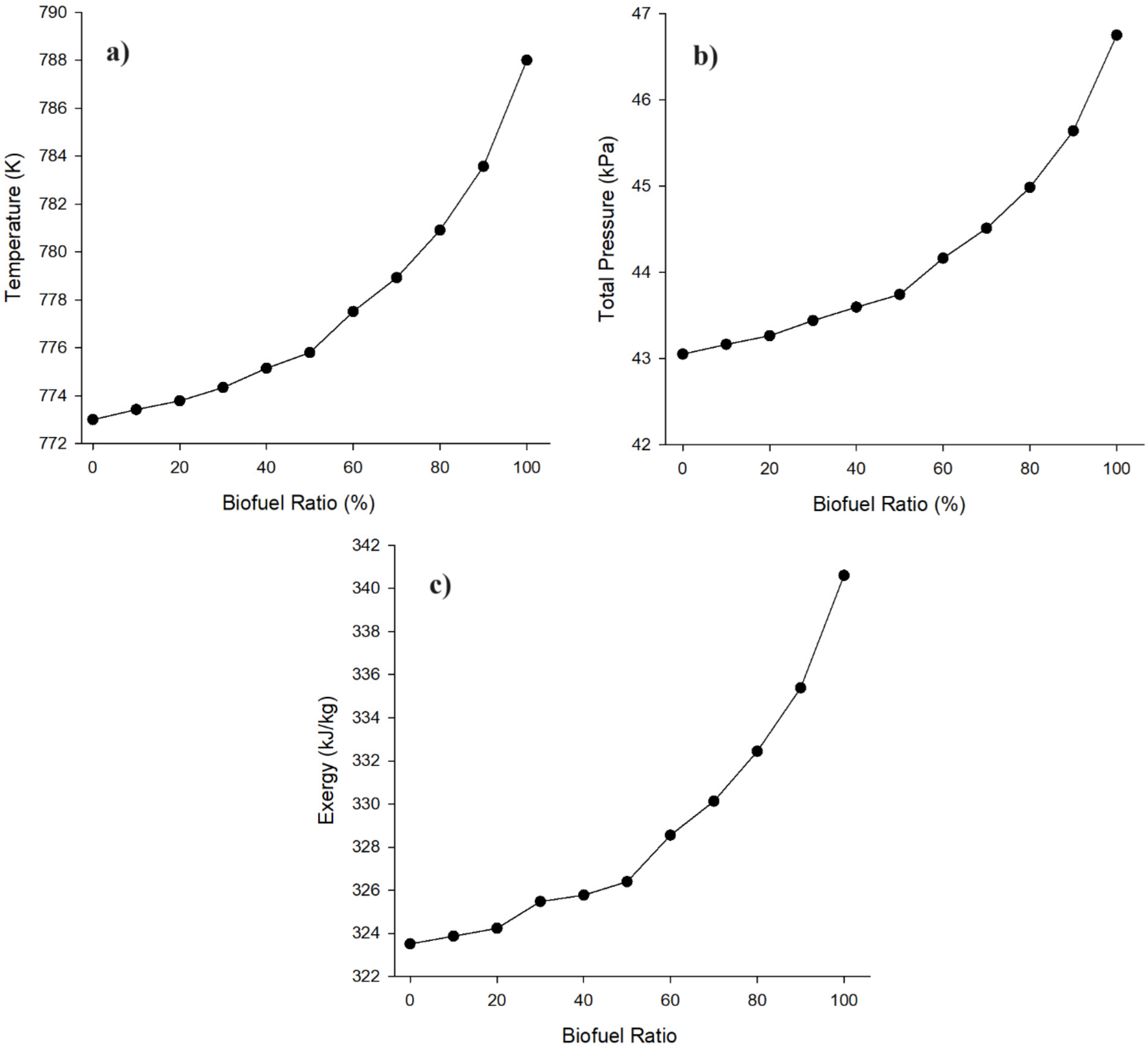

Figure 3. Effect of biofuel addition on engine performance parameters a) LPT Exit Temperature, b) Nozzle Total Pressure, c) Nozzle Exergy

4. CONCLUSION

In this study, the effect of biofuel addition on performance criteria in a gas turbine engine with high bypass ratio was investigated. In the study using a numerical modeling program; Net thrust, exergy and total pressure values were analyzed. As a result of the analysis, the following results emerged;

- Lower exergy loss occurred as a result of lower adiabatic flame temperature of biofuel and lower calorific value.
- A high total pressure value was obtained at the nozzle exit of the engine, in parallel with the high exergy. Less pressure loss means a more efficient system.
- Net thrust increased as the biofuel ratio increased due to both an efficient system and the increase in the total air + fuel flow rate expelled from the nozzle.

NOMENCLATURE

CO_2	Carbon Dioxide
CO	Carbon monoxide
NO_x	Nitrogen Oxide
HP	High Pressure
LP	Low Pressure
HPC	High Pressure Compressor

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DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Gamze Polatlı: Writing, Analysis, Methodology, Methodology, Investigation.

Şule Çitil: Analysis, Methodology.

Mustafa Akbudak: Analysis, Methodology, Project Administration, Resources, Investigation.

Buğrahan Alabaş: Writing, Analysis, Methodology, Methodology, Investigation, Visualization, Supervision, Writing – Review & Editing, Visualization.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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