Research Article

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The Combustion and Emission Characteristics of Corn Oil Biodiesel with Titanium Oxide (TiO_2) Nano-additive

Surakasi Raviteja[1*], K. Ch. Sekhar[1], Sundara Ramam Rapeta[2], D. Bhanuchandra Rao[3] and B. Ushaswini[1]

[1]Department of Mechanical Engineering, Lendi Institute of Engineering and Technology, Jonnada, Vizianagaram, AP, India
[2]Department of Mechanical Engineering, Vignan's Institute of Information Technology, Duvvada, Visakhapatnam, AP, India
[3]Department of Mechanical Engineering, Aditya Institute of Technology and Management, Tekkali, AP, India
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*ravitejasurakasi@gmail.com

ABSTRACT

This experiment produced biodiesel from corn oil through transesterification. Fuel mixture proportions were changed to assess engine performance and reduce fossil fuel emissions. This study examined brake power, mean effective pressure, mechanical efficiency, brake thermal efficiency and indicated thermal efficiency, and emissions such as hydrocarbons, carbon monoxide and NO_x. 20% of corn oil was blended with diesel to make biodiesel. The fuel characteristics of the corn oil methyl ester matched ASTM standards. Experimental results were obtained by operating a single-cylinder four-stroke diesel engine under various load conditions. Titanium oxide nanoparticles in the biodiesel reduced HC and CO engine emissions whereas, there was an increase in CO_2 and NOx emissions. Combustion parameters such as cumulative net heat release rate and fuel line pressure decreased whereas, cylinder pressure and net heat release rate increased; the sample BD20 + 100 ppm TiO_2 sample exhibited appreciable results.

Keywords: Corn oil; Biodiesel; Transesterification; Engine; Internal combustion; Environmental pollution.

1. INTRODUCTION

Biodiesel has emerged as a promising substitute for fossil fuels in internal combustion engines (ICE), stoves, and other burners due to the growing need for clean energy (Zhanming *et al.* 2020). Policies that encourage the manufacture and widespread consumption of first-generation biodiesel inside national borders initiated biofuel's rising popularity in many countries. The cultivation of oil palm has been promoted in some nations as a means to produce biodiesel, which may be used to fulfill the energy requirements for power generation (Raviteja *et al.* 2023). It should be mentioned that there are several downsides to first-generation biofuels, such as the high water consumption during their manufacture, which might threaten food supplies, and competing with crops meant for human consumption. This sparks a discussion on the efficacy of using food and energy from these resources, which is crucial to the development of novel strategies in certain countries. Owing to such discrepancies, efforts to create new solutions and materials are intensified. Second-, third-, as well as fourth-generation biofuels made from non-food crops and various other materials are the focus of many of these activities (Souad *et al.* 2017). The creation of biodiesel from non-food sources and the subsequent application of this fuel led to various perspectives on the possible food and fuel production from these sources, which calls for a careful evaluation of this factor throughout the legislation process in various nations. There have been several in-depth studies conducted by academics from all around the world on the topic of the efficiency of internal combustion engines (Subramaniam *et al.* 2020). Biodiesel producing non-edible vegetable oils has been the subject of an extensive online investigation, detailing the fuel's properties and performance. Various plant oils, including those extracted from rubber trees, cotton plants, jojoba trees, tobacco plants, flax plants, jatropha plants, and various others, have been investigated by scientists as possible raw material sources. Growing oil palms for biodiesel has been promoted in various countries to meet the demand for this fuel source in electric generators (Boreum *et al.* 2020). In 2012, Philippines became the first country to begin producing biodiesel made from olive oil. First-generation biofuels have several disadvantages, including competition with food crops and high water use in production. It was shown that biodiesel could be produced from corn oil in a way that is consistent with global environmental regulations and guidelines (Yaopeng *et al.* 2020). Comparably, the researchers developed an integrated catalytic method to produce biodiesel using a composite membrane and sodium methoxide. The study's authors concluded that a 98.1% transesterification conversion rate is achievable under ideal conditions for the production of biofuel. In recent years, several scientists are devoting much time and energy to determine whether biodiesel may be utilized as a viable fuel for internal combustion engines. Recent studies have investigated transportation-related internal combustion engine efficiency (Le *et al*. 2020).

2. MATERIALS AND METHOD

2.1 Biodiesel Production

According to the Food and Agriculture Organization (FAO), the first step involves the extraction of corn oil by heating procedures, resulting in an approximate output of 10 liters of oil. A specimen of this oil was used to conduct acidity analysis. The presence of free fatty acids inside a triglyceride is denoted by its acid number, which serves as an indicator of its acidity. The use of potassium hydroxide for titration is deemed essential, whereas the quantification of acidity is accomplished by the acid number index. The analysis will ascertain the acid number of the oil (Sunil *et al*. 2024). If the determined value is less than or equal to 5, it indicates a suitable working condition without complications. However, an acidity index exceeding 5 is not advisable for biodiesel production due to the elevated acid number. However, it is not ideal for biodiesel production and has greater use elsewhere. The acidity was determined by mixing a 5-gram sample with 50 ml of neutralized ethyl alcohol around 50 °C. After that, a few drops of phenolphthalein were added to the mixture in an Erlenmeyer flask. Thereafter, a 0.1 N potassium hydroxide solution was used to titrate the solution (Uyumaz, 2020). The transesterification process is shown in Fig. 1.

The method of transesterification is used on renewable lipids like vegetable and animal oils to produce monoalkyl esters made up of long-chain fatty acids. This procedure may also be used on animal fats. After that, these esters are included in the manufacturing of biodiesel. As part of the procedure for the experiment, 10 liters of used cooking oil was poured into the container that was specifically prepared for their disposal (Raviteja *et al*. 2022). After that, an amount of methanol with a concentration of 20% (v/v) was added to the container. The volume of the methanol was comparable to that of the oil sample that was being analyzed. To calculate the amount of catalyst needed, an additional quantity equivalent to the acid number was added to the total. 8 g of potassium hydroxide (KOH) was added, which brought a discernible reaction. Then, the catalyst and methanol (the methoxide) were mixed; the sample was then given the catalyst-methoxide combination to react with. After that, the resultant mixture was agitated for about two hours at a temperature ranging from 50 to 60 °C. The glycerine went through a decantation process, and then it was separated. After that, a series of three to four washes with water was carried out, each with a concentration of water ranging from twenty to thirty percent (v/v), depending on the amount of biodiesel produced. Eventually, the operations of drying and filtration, as indicated in the reference, were carried out (Chao *et al*. 2019).

2.2 Fuel Samples

To generate the corn oil methyl ester blend (B20) for further evaluation, a magnetic stirrer was used to thoroughly mix a volumetric combination of 20% biodiesel and 80% diesel. The aforementioned process resulted in the outcome. Titanium oxide (TiO_2) nanoparticles were uniformly dispersed in B20 fuel test samples using an ultrasonicator, following the previously mentioned protocol. The dosage levels used were 25, 50, 75 and 100 parts per million (ppm). The ASTM D 6751 test technique, a widely accepted standard method for assessing fuel attributes, was used to evaluate the quality of the fuels. The properties of various fuel blends used are presented in Table 1.

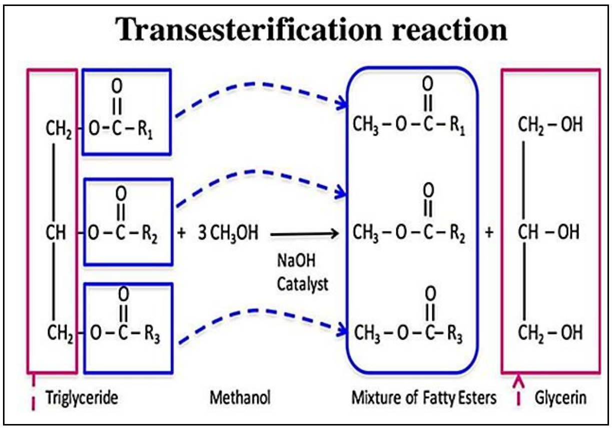

Fig. 1: Transesterification process

Table 1. Properties of fuel blends

	Diesel	BD20	BD20 + 25 ppm TiO_2	BD20 + 50 ppm TiO_2	BD20 + 75 ppm TiO_2	BD20 + 100 ppm TiO_2
Density (kg/m^3)	815	820	826.5	833	839.5	846
Viscosity (mm^2/s)	3.1	3.2	3.3	3.4	3.5	3.6
Calorific Value (MJ/kg)	44	43	43.75	44.5	45.25	46
Cetane Number	52	56.6	57.05	57.5	57.95	58.4
Flash Point (°C)	205	195.6	196.3	197	197.7	198.4
Fire Point (°C)	58	130.4	131.25	132.1	132.95	133.8

3. EXPERIMENTAL SET-UP

For the test, a Kirloskar, TV1 type engine (a single-cylinder, four-stroke, compression-ignition engine) was used; it was paired with a water-cooled and water-injected cooling system. This particular engine had valves that were driven by pushrods. The engine has the potential to create an output power of 5.2 kW in circumstances of maximum effort while still maintaining a rotational speed of 1500 rpm. This is the greatest power that it is capable of producing. The manufacturer's guidelines were followed; the fuel injection pressure and timing were maintained at 210 bar and 23° before top dead center (TDC), respectively. The temperature of the coolant was maintained at a stable level of 80 °C for the whole of the operation. A mechanism that allowed for constant recirculation of the coolant via the water jackets housed inside the cylinder made this feasible. A piezoelectric transducer positioned flush on the cylinder head of the vehicle was used to measure the pressure within the engine's cylinders. To measure the engine's torque production, an eddy current dynamometer was incorporated. The experimental setup is shown in Fig. 2, which illustrates the schematic design.

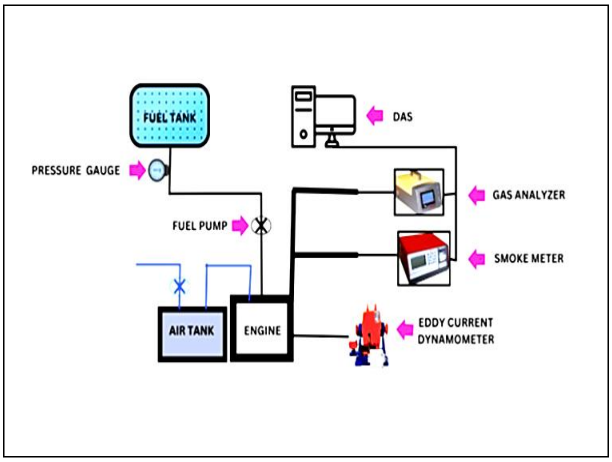

Fig. 2: Experimental set-up

4. RESULTS AND DISCUSSION

4.1 Emission Characteristics

4.1.1 HC Emission Test

The data shown in Fig. 8 demonstrates that the emission levels of HC grow in both low-load and high-load conditions, approaching maximum power. Based on the theoretical framework, the limited availability of oxygen leads to an elevation in the concentration of HC emissions. This implies that the fuel has a higher level of richness in comparison to the fuel-air mixture ratio. Fig. 3 illustrates that across the operational range, the HC emission is consistently reduced for all mixtures. Furthermore, it is seen that the combination including B20 + 100 ppm TiO_2 exhibits even lower emissions compared to the B20 mixture (Zhanming *et al*. 2020).

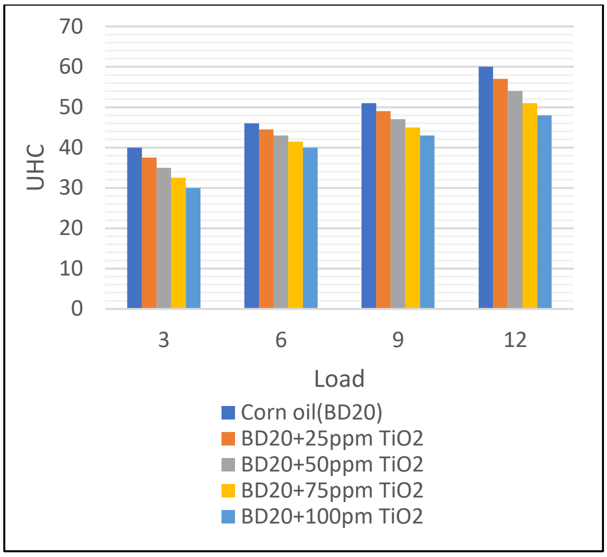

Fig. 3: HC *vs.* Engine load

4.1.2 CO Emission Test

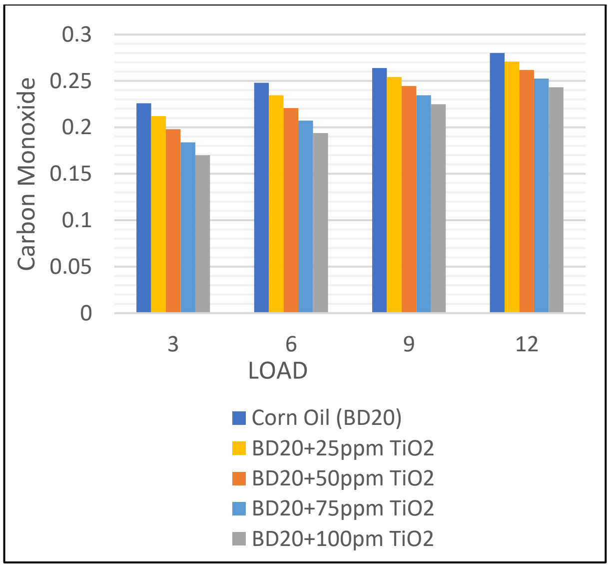

Fig. 4: CO *vs.* Engine load

From Fig. 4, a positive correlation is evident between the emission of carbon monoxide (CO) and the growth in all loads. When considering the use of fuel blended with corn oil biodiesel, it is seen that the aforementioned data demonstrates a significant decrease of around 20 to 25% in overall CO emissions. The maximum concentration of carbon monoxide (CO) is often found in the general atmosphere, including the combination of B20 blend. The use of B20 fuel blend augmented with 100 parts per million of TiO_2 has the potential to significantly mitigate the release of greenhouse gas emissions.

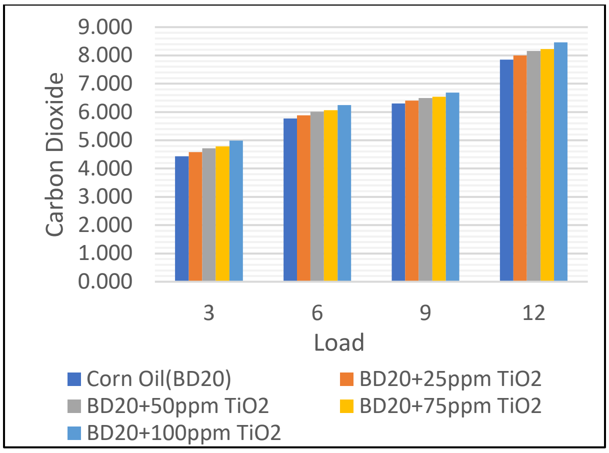

Fig. 5: CO_2 *vs.* Engine load

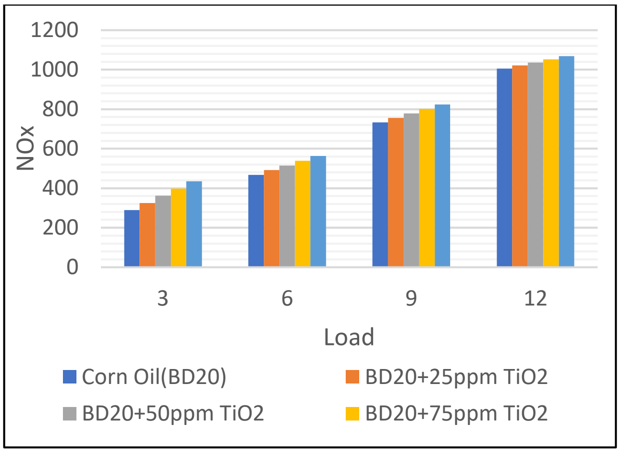

Fig. 6: NO_x *vs.* Engine load

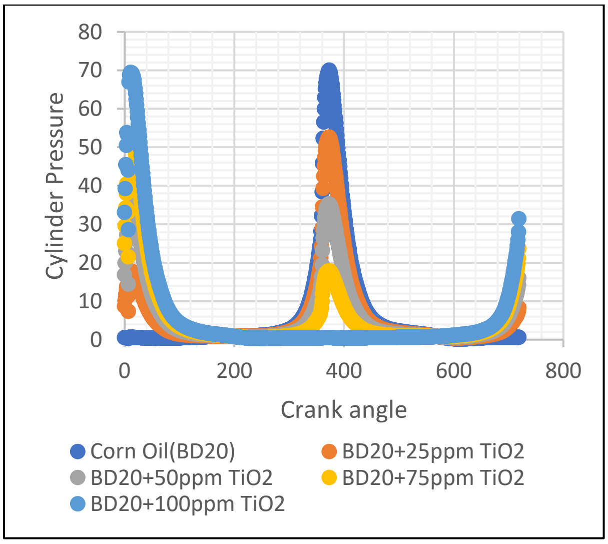

Fig. 7: Cylinder pressure *vs.* Crank angle

4.1.3 CO_2 Emission Test

From the data shown in Fig. 5, a positive correlation is evident between the emission of CO_2 and the growth in all loads. When considering the use of fuel blended with waste cooking oil biodiesel, it is seen that the aforementioned data demonstrates a significant increase in overall CO_2 emissions (Changming *et al.* 2019). It illustrates that across the operational range, the CO_2 emission is consistently increasing for all mixtures. Furthermore, it is seen that B20 + 100 ppm TiO_2 mixture exhibits higher emissions compared to the B20 mixture (Zhiyong *et al.* 2019).

4.1.4 NO_x Emission Test

Based on the data shown in Fig. 6, a positive correlation is evident between the emission of NO_x and the growth in all loads. When considering the use of fuel blended with waste cooking oil biodiesel, it is seen that the aforementioned data demonstrates a significant increase in overall NO_x emissions. It illustrates that the NO_x emission is consistently increasing for all mixtures across the operational range. Furthermore, it is seen that the combination including B20 + 100 ppm TiO_2 exhibits higher emissions compared to the B20 mixture (Reham *et al.* 2015).

4.2 Combustion Characteristics

The combustion characteristics of the prepared samples have been carried out at maximum load of 12 kg and plotted by taking crank angle on X-axis and combustion parameters on Y-axis.

4.2.1 Cylinder Pressure

Fig. 7 shows the graph drawn between cylinder pressure and crank angle at a load of 12 kg. It can be seen that BD20 + 100 ppm TiO_2 has resulted in maximum cylinder pressure when compared to the remaining samples and it can be concluded that increasing the concentration of nanopowder shows a positive trend with an increase in the cylinder pressure (Le *et al.* 2020b).

4.2.2 Cumulative Heat Release Rate

Fig. 8 shows the graph drawn between cumulative heat release rate and crank angle at 12 kg load. It can be seen that BD20 + 100 ppm TiO_2 has the minimum cumulative heat release rate when compared to the remaining samples and it can be concluded that increasing the concentration of nanopowder shows a declining trend in cumulative heat release rate (Surakasi and Velivela, 2022).

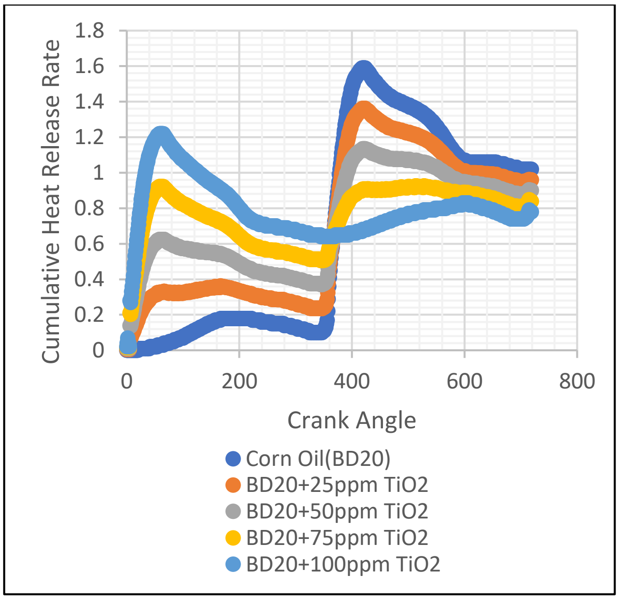

Fig. 8: Cumulative heat release rate *vs.* Crank angle

4.2.3 Net Heat Release Rate

Fig. 9 shows the graph drawn between the net heat release rate and crank angle at a 12 kg load. It can be seen that BD20 + 100 ppm TiO_2 has the maximum net heat release rate when compared to the remaining samples and it can be concluded that increasing the concentration of nanopowder shows an increase in net heat release rate (Venu and Madhavan, 2017).

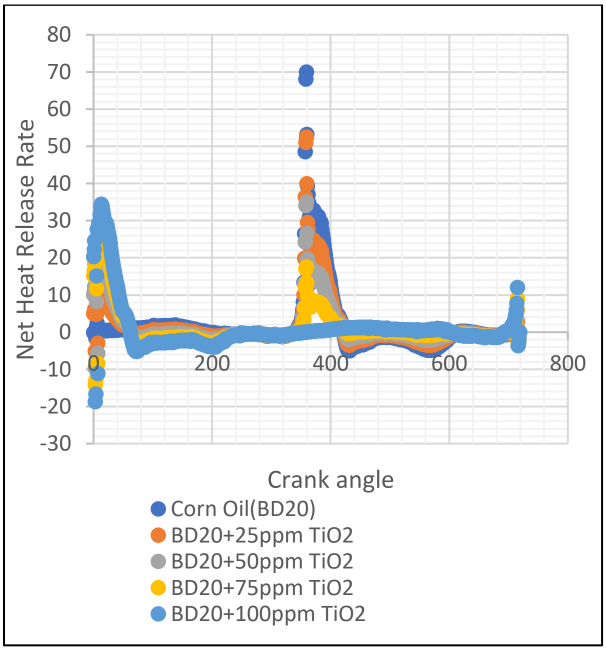

Fig. 9: Net heat release rate *vs.* Crank angle

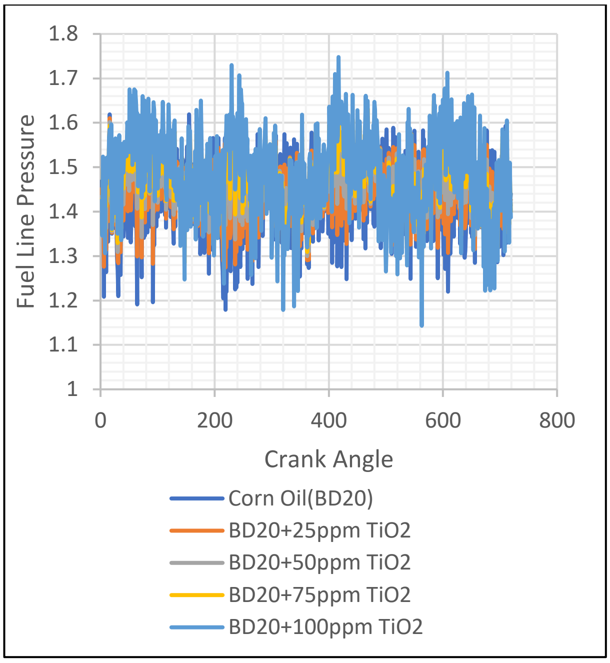

Fig. 10: Fuel line pressure *vs.* Crank angle

4.2.4 Fuel Line Pressure

Fig. 10 shows the graph drawn between fuel line pressure and crank angle at a 12 kg load. It can be seen that BD20 + 100 ppm TiO_2 has the minimum fuel line pressure when compared to the remaining samples and it can be concluded that increasing the concentration of nanopowder shows a declining trend in fuel line pressure (Swarup *et al*. 2022).

5. CONCLUSION

20% of corn oil was blended with diesel to make biodiesel. The fuel characteristics of the corn oil methyl ester matched ASTM standards. Experimental results were obtained by operating a single-cylinder four-stroke diesel engine under various load conditions. TiO_2 nanoparticles in B20 substantially reduced HC and CO engine emissions whereas, CO_2 and NOx emissions increased. Combustion parameters such as cumulative net heat release rate and fuel line pressure decrease whereas, cylinder pressure and net heat release rate increase and the sample BD20 + 100 ppm TiO_2 exhibits the minimum and maximum values, respectively. Overall, it can be concluded that BD20 + 100 ppm TiO_2 sample showed the best results.

DATA AVAILABILITY STATEMENT

The paper incorporates the data used to substantiate the conclusions of this investigation.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest with this manuscript's publication.

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