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Investigation of the Usability of Biodiesel from Horse Oil in Diesel Engines

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HIGHLIGHTS

- Biodiesel is an alternative diesel fuel produced from animal and vegetable oils.
- It was concluded that the cold flow properties of horse oil biodiesel are not suitable for diesel engines.
- Horse oil biodiesel production stages and determination of fuel properties contributed to the usability of horse oil biodiesel for diesel engines.

Abstract

Biodiesel is an alternative diesel fuel produced from animal and vegetable oils. As an alternative and ecologically acceptable substitute for conventional fuel, biodiesel is produced from a wide variety of edible vegetable oils that are usually used for human consumption and whose prices are expected to rise in the future. In this context, reliable and low-cost raw materials are gaining increasing interest for biodiesel production, such as by-products of meat processing industries or waste animal fats. Biodiesel production from waste animal fat, and raw food does not compete with the industry and has a great potential for waste caused by the global decline. In our study, a potential alternative fuel was produced for diesel engines by using the non-food-grade fat portion of horse meat consumed in Middle Asia countries. Solid crude horse oil was liquefied, and its fatty acid components were analyzed and transformed into horse oil biodiesel by the transesterification method. It was determined whether the fuel properties of crude horse oil, horse oil biodiesel, and euro diesel fuel comply with the standard values, and their usability in diesel engines was investigated. As a result of the tests, it has been concluded that horse oil biodiesel does not meet the standards in terms of cold flow properties and can only be used at a rate of low volumetric ratios in diesel engines. This article will contribute to the use of horse oil biodiesel production stages and fuel properties in diesel engines and future studies.

Keywords: Euro diesel, *Fuel properties*, Horse biodiesel, *Horse oil*, Standards

1. Introduction

The oil and fat materials used as raw materials are estimated to represent 60% to 80% of the total cost of biodiesel production (Busic et al. 2018). Therefore, it is important to choose the best materials in each case, as they are influenced by geographic location, agriculture and climate (Mahlia et al. 2020). One of the main applications of inedible animal fat products is biodiesel production (Baladincz and Hancsok 2015).

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Compression ignition engines it is considered to be an ideal alternative biodiesel fuel (Keskin et al. 2020). Biodiesel, with about 10% to 15% oxygen content, non-toxic, biodegradable, and renewable fuel and its combustion behavior is similar to that of petroleum-based diesel fuel. Therefore, today's modern compression ignition engines can be fueled with biodiesel without any modification (Ağbulut et al., 2019). The alternative fuel must be technologically acceptable, environmentally friendly, economically competitive and easily accessible (Snader et al. 2018). The greatest potential is seen in biodiesel emissions because previous studies have shown that biodiesel combustion is greatly reduced, so biodiesel is currently the most widely used renewable energy source (Guru et al. 2010). In addition to reduced emissions, the transportation sector, biodiesel production, which will ease its dependence on fossil fuels and to a great extent available, thanks to renewable and environmentally friendly raw materials will promote economic development (Chakraborty et al. 2014). Biodiesel consists of mono-alkyl esters of long-chain fatty acids produced from fat or oil, but the use of vegetable oil adds a high price to biodiesel, which has led to the use of animal fats as an interesting alternative to biodiesel (Reig et al. 2020). In addition to its renewable league, biodiesel is an alternative because it offers better lubrication than diesel fuel. At the same time, biodiesel has a high flash point (Nigam et al. 2011). Biodiesel also contributes to sustainability by reducing its carbon footprint, as it produces lower CO_2 emissions compared to fossil diesel fuel (Mansir et al. 2018). Biodiesel can be mixed with diesel fuels up to 20% in most countries, and can be used without the need for engine modification (Gumahin et al. 2019). Biodiesel is named as B_5, B_{10} or B_{20} for blends of 5%, 10% and 20% respectively, in terms of volume content. Today, more than 78% of diesel vehicles that come off production lines are approved for use at B_{20} (Anonymous 2020). Biodiesel must comply with EN 14214 in Europe and ASTM 6751 in the USA to be blended with normal fossil diesel (Efpra 2016). Behçet et al. (2015), produced biodiesel from fish oil and chicken oil, examined its fuel properties, and mixed 20% of the biodiesel they produced into diesel fuel. They have obtained performance and emission results by testing their test fuels in a single-cylinder four-stroke diesel engine. According to the test results, they determined that mixed fuels increased NO_x emission and specific fuel consumption compared to diesel fuel, and reduced power, moment, CO, CO_2 and HC emissions.

The innovative aspect of this study is that there is no study in the literature on horse oil biodiesel production. Due to the limited sources of alternative fuel used in internal combustion engines, we have determined in our research that horse meat consumed as food in Middle Asia countries is a potential alternative fuel that does not have the quality of food and is not used. Thanks to the horse oil biodiesel production stages and fuel properties, its usability in diesel engines will be determined with this study and will shed light on future studies.

2. Materials and Methods

In this study, biodiesel production was carried out from crude horse oil imported from Kyrgyzstan's capital Bishkek. In the production stages, methyl alcohol was used as alcohol and sodium hydroxide was used as a catalyst. Production was carried out by the transesterification method in Selcuk University Biodiesel Laboratory. Euro diesel fuel was provided from BP Company. The fuel properties of the horse oil biodiesel and euro diesel oil produced were measured in the laboratory in accordance with the standards and the analysis results are given in Table 1. In addition, during the measurements, occupational safety rules were observed. During the production stages; 1 kg of solid horse oil was chopped into small pieces, heated up to its melting temperature in a container, and the cartilage structure was removed and the oil became liquid after the water evaporated was filtered and taken into a beaker. The crude horse oil in liquid form was filtered again in a paper filter and heated up to 110 °C in a heated magnetic stirrer, and the water contained in it was removed from the oil (Figure 1).

Figure 1. Crude horse oil (solid-liquid)

Table 1. Analysis results of the test fuels

Characteristic	The Units	Crude Horse Oil	Horse Oil Biodiesel	Euro Diesel Fuel	Limiting Value	
					TS EN 590 Diesel	TS EN 14214 Biodiesel
Color Determination	ASTM 1500 (0,5 – 8 unit)	5,4	3,5	1,2	--------	--------
Density (at 15^{0}C)	g/cm^3	0,9088	0,8728	0,8331	0,82 - 0,84	0,86 – 0,90
Kinematic Viscosity (at	mm^2/s	37,869	4,999	3,065	2 - 4,5	3,5 - 5
Flash Point	^{0}C	180	122	60	Min 55	Min 120
CFPP	^{0}C	6,2	8,9	-12,5	-20	--------
pH	——	6	5	4	--------	--------
Cloud Point	^{0}C	8,7	11,9	-8,1	--------	--------
Pour Point	^{0}C	1,8	5,2	-14	--------	--------
Freezing Point	^{0}C	0,2	0,5	-20	--------	--------
Copper Rod Corrosion	——	1a	1a	1a	No:1	No:1
Calorific Value	Cal/gr	8962	9284	9858	--------	--------

In the production by the transesterification method, 150 ml methanol and 2.7 gr sodium hydroxide mixture were made for 600 ml crude horse oil and methoxide was formed. Since the sample is animal fat, the molar ratio was 5.5: 1. In production, crude horse oil was treated with a magnetic stirrer with heater in a beaker at 55 0C for 1 hour reaction time. Then, after waiting 12 hours, the decomposition of glycerin was observed. The decomposed crude biodiesel was placed in another beaker and washed in a 50% distilled water shower method (Figure 2).

Figure 2. Horse oil Biodiesel production stages

Then, by waiting 12 hours, phase separation was achieved, and the crude biodiesel was heated at 110 ^{0}C for 120 minutes on a heated magnetic stirrer and the water in it was removed. Thus, biodiesel production was realized from horsefoot (Figure 3).

Figure 3. Horse oil biodiesel final form

2.1. Fatty Acid Components of Horse Oil

The fatty acid components of horse oil used in biodiesel production were measured in Necmettin Erbakan University Engineering and Architecture Faculty Food Engineering Laboratory. In the preparation of fatty acid methyl esters, the In Situ method of Park and Goins (1994), was modified and used. According to this; After taking 150 µL of the sample, adding 100 µL dichloromethane and 1 mL 0.5 N methanolic NaOH, waiting at 90 ^{0}C for 10 minutes, cooling at room temperature, adding 1 mL of 14% methanolic BF_3, waiting at 90 ^{0}C for 10 minutes, cooled down. Then 1 mL of distilled water, 500 mL of hexan were added, mixed for 1 minute in the vortex, centrifuged. (5 minutes / 2500 rpm) Sodium sulfate was added. After the phase separation took place, it was taken from the clear phase in the upper layer into vials of 2 mL volume and stored in the deep freezer to be injected into the GC. Fatty acids and analyses of oil samples converted into methyl esters are given in the Shimadzu GC-2025 model Gas Chromatography device, flame ionization detector (FID) and qualifications are given in Figure 4; It was constructed using HP-Innovax capillary column (L: 30m, ID: 0.25mm, DF: 0.25µm). The temperature program for the method is given in Figure 5; detector temperature: 240 ^{0}C, injector temperature: 250 ^{0}C, column (furnace) temperature: 2 minutes at 70 ^{0}C, 15 ^{0}C/min to 220 ^{0}C; Waiting time at 220 ^{0}C is 2 minutes; from here 250 ^{0}C to 3 ^{0}C/min; Waiting time at 250 ^{0}C 10 minutes, total analysis time: 34 minutes. Injection: Split 1: 100. Gas flow rates: carrier gas: helium 3 ml/min (constant flow pattern); hydrogen, 40 mL/min; dry air was set at 400 mL/min. The sample was injected into the instrument 1 µL. For the diagnosis of fatty acids, a mixture of methyl esters of fatty acids Supelco 37 Component FAME Mix (Sigma-Aldrich Co. USA) Food Industry FAME Mix 37 components (Restek Corporation USA) was used as a standard. Chromatograms of fatty acid methyl esters and ratios of fatty acids were obtained on computer by SHIMADZU GC solution program. The peaks in the chromatograms of the analyzed samples were identified by comparing the retention times of the methyl esters of all fatty acids in the standard and benefiting from professional experience. The results are given as a qualitative value in% fatty acid. The chromatography image is given in Figure 6.

Oils gain value according to the fatty acids they contain and their ratios. Fats in terms of chemical structure; are collected in 3 groups saturated, monounsaturated and polyunsaturated oils. These three groups are present in all oils, but their proportion varies according to the oil type. The ratio of unsaturated fatty acids to saturated fatty acids (P/S) in oils is an important quality factor. The higher this ratio, the higher the conversion rate of fats into ester.

Figure 4. Column attributes

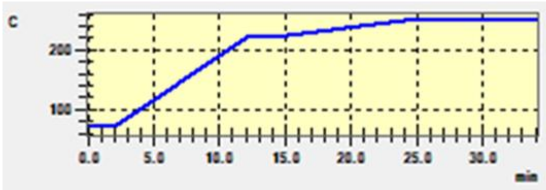

Figure 5. Temperature program

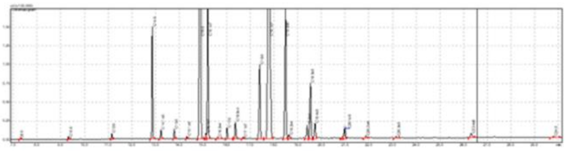

Figure 6. Chromatogram

Table 2. Fatty acid components

Analysis	Unit	Analysis Result
Caprylic Acid	C8:0	0,024
Capric Acid	C10:0	0,081
Lauric Acid	C12:0	0,184
Myristic Acid	C14:0	3,768
Nervonic Acid	C15:0	0,370
Palmitic Acid	C16:0	28,246
Palmitoleic Acid	C16:1	0,242
Margaric Acid	C17:0	0,507
Stearic Acid	C18:0	4,395
Oleic Acid	C18:1	38,640
Linoleic Acid	C18:2	7,247
Linolenic Acid	C18:3	0,821
Arachidic Acid	C20:0	0,113
Gadeloic Acid	C20:1	0,582
Behenic Acid	C22:0	0,402
Lignoceric Acid	C24:0	0,225

Animal oils are rich in saturated fatty acids. The fatty acid compositions of the oil are given in Table 2. As seen in Table 2, horse oil's myristic fatty acid amount is 3,768%, the palmitic acid amount is 28,246%, stearic fatty acid amount is 4,395%; It is an oil with a good oleic acid amount of 38,640 and a linoleic acid amount of 0,821. The horse oil used in the research is a medium-value oil in terms of oleic acid amount and linoleic acid amount. In this case, it is possible to say that oils containing long, branched and single double-bonded fatty acids are suitable diesel alternatives. Some properties of biodiesel depend on the raw material from which it is obtained. Fatty acids used in biodiesel production are grouped as saturated, mono and polyunsaturated. However, ideal biodiesel can only be made from monounsaturated fatty acids. For this reason, it is desirable that the monounsaturated fat content of the oil to be produced biodiesel should be high. Oxidation resistance is better in high oleic acid oils. The composition of common vegetable oils varies as the ratio of the different types of fatty acid chains in each oil. The proportions of these chains affect the physical properties of each fluid. Monounsaturated chains are good for oxidation resistance. Polyunsaturated chains give poor oxidation resistance but improve low-temperature behavior. The low-temperature resistance of the saturated fatty acid chain is very low. Since the saturated fatty acid component of horse oil is high, oxidation resistance and cetane number are expected to be good. However, as the saturation increases, the cold flow properties may not be very good (Öğüt and Oğuz 2006).

3. Results and Discussion

3.1. Color specification

When the color specification test results were examined, it was seen that the crude horse oil color was darker than the horse oil biodiesel. Euro diesel fuel is the lightest colored among the test fuels (Figure 7). When horse oil is examined in terms of biodiesel color values, it is appropriate to use it as fuel in diesel engines according to ASTM 1500 standards.

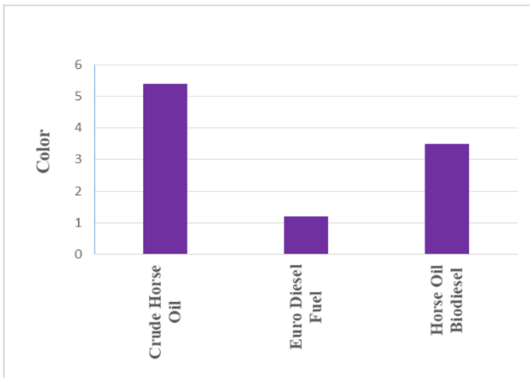

Figure 7. Color test results of fuels (ASTM 1500)

3.2. Density

When the test results were examined, it was determined that the density of crude horse oil was higher than other test fuels, and the density values of horse oil biodiesel and euro diesel fuels were at standard values. This shows the usability of horse oil biodiesel in diesel engines (Figure 8).

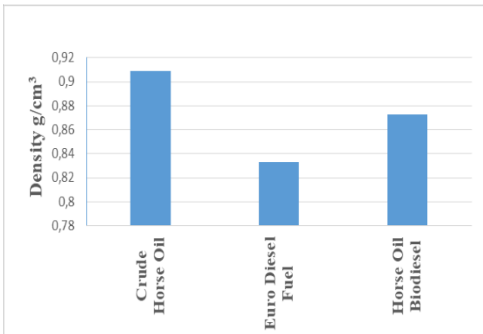

Figure 8. Density test results of fuels

3.3. Kinematic viscosity at 40 °C

The viscosity value should be low enough to allow the fuel to flow easily even at low operating temperatures. When the test fuels are examined, it shows that their kinematic viscosity at 40 ^{0}C is high in crude horse oil, horse oil is at standard values in biodiesel and euro diesel fuels and is within the limits that can be easily used in diesel engines (Figure 9).

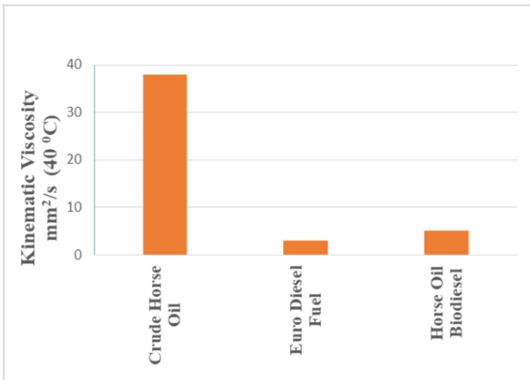

Figure 9. Kinematic viscosity test results of fuels at 40 ^{0}C

3.4. Flash point

When the flash point test results are examined, it is seen that the flash point value of crude horse oil is high, while horse oil biodiesel and euro diesel fuel are within standard values. Horse oil biodiesel and euro diesel fuels can be easily used in diesel engines in terms of their flash point values (Figure 10).

3.5. Cold filter plugging point (CFPP)

When the test results are examined, it is seen that the cold filter plugging point values of crude horse oil and horse oil biodiesel are not 100% suitable for use in diesel engines compared to euro diesel fuel. For this reason, horse oil can be used by mixing biodiesel with diesel at low volumetric ratios (Figure 11).

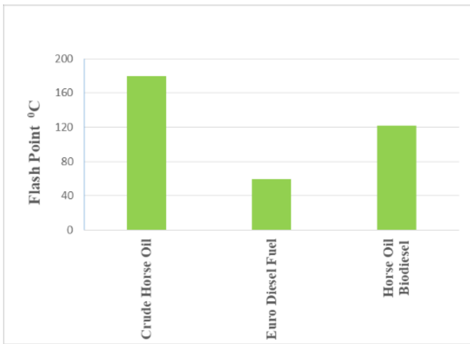

Figure 10. Flash point test results of fuels

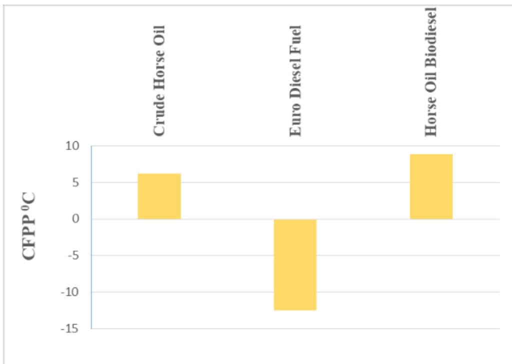

Figure 11. CFPP test results of fuels

3.6. pH

When the PH value test results of the fuels were examined, it was determined that the pH values were below 7 and acidic. In this respect, all test fuels are within the limit values used in diesel engines in terms of pH value (Figure 12).

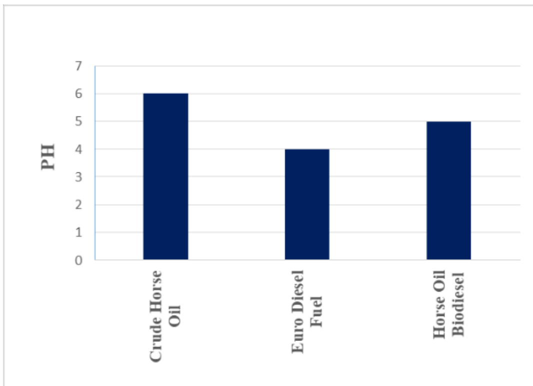

Figure 12. pH test results of fuels

3.7. Cloud point

When the test results are examined, it is seen that the cloud point values of crude horse oil and horse oil biodiesel are not 100% suitable for diesel engines compared to euro diesel fuel. This is a disadvantage for the engine to run in cold conditions. For this reason, horse oil can be used by mixing biodiesel with diesel at low volumetric ratios (Figure 13).

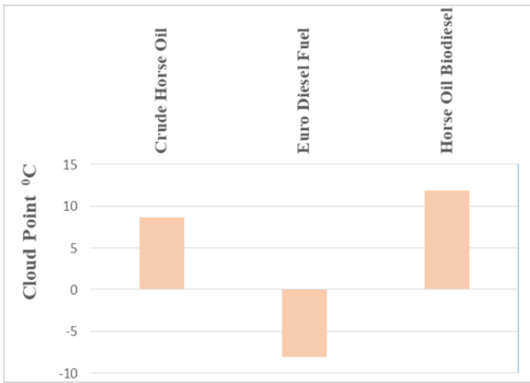

Figure 13. Cloud point test results of fuels

3.8. Pour point

When the test results are examined, it has been determined that the pour point values of crude horse oil and horse oil biodiesel are not 100% suitable for diesel engines compared to euro diesel fuel, and this will cause problems such as late starting and ignition difficulty for the engine to run in cold weather. For this reason, horse oil can be used by mixing biodiesel with diesel at low volumetric ratios (Figure 14).

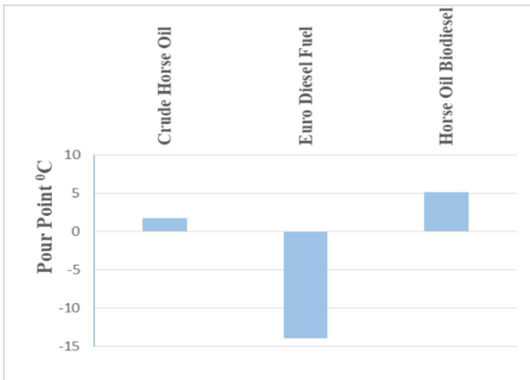

Figure 14. Pour point values of the test fuels

3.9. Freezing point

When the test results are examined, the freezing point values of crude horse oil and horse oil biodiesel are positive values, as shown in Table 1, while the values for euro diesel fuel are -20 ^{0}C. This shows that crude horse oil and horse oil biodiesel are not 100% suitable for diesel engines compared to euro diesel fuel. For this reason, horse oil can be used by mixing biodiesel with diesel at low volumetric ratios (Figure 15).

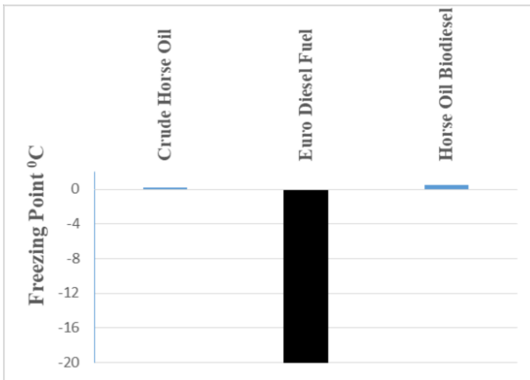

Figure 15. Freezing point test results of fuels

3.10. Copper rod corrosion

When the copper rod corrosion test results of test fuels were examined, a 1a value was obtained for all fuels. Therefore, the results could not be shown graphically.

3.11. Calorific values

When the test results are examined, it is seen in Table 1 that the calorific value of horse oil biodiesel is close to that of euro diesel fuel. This shows that horse oil biodiesel can be used in diesel engines without any problems in terms of thermal value (Figure 16).

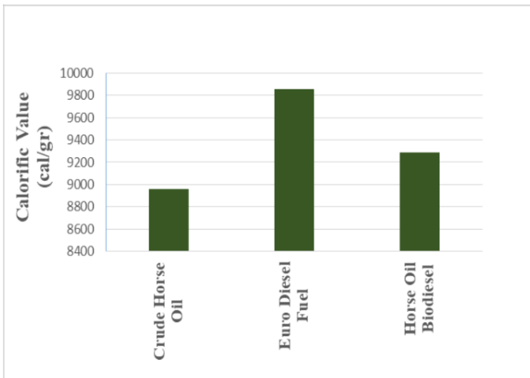

Figure 16. Calorific values test results of fuels

4. Conclusions

As a result of this study;

- It was concluded that the cold flow properties of horse oil biodiesel are not suitable for diesel engines.
- As the amount of Capric Acid, Lauric Acid (C12:0), Myristic Acid (C14:0), Palmitic Acid (C16:0), Stearic Acid (C18:0) increases, the cold flow properties increase. So, it gets worse. It gets better as the number of ligaments increases.
- However, it has been concluded that can be used by mixing horse oil biodiesel with diesel at low volumetric ratios.

- Horse oil biodiesel production stages and determination of fuel properties contributed to the usability of horse oil biodiesel for diesel engines.

Abbreviations

^0C	Celsius Degree
ASTM	International American Society for Testing and Materials
B_5	5 % Biodiesel
B_{10}	10 % Biodiesel
B_{20}	20 % Biodiesel
B_{50}	50 % Biodiesel
B_{100}	100 % Biodiesel
CFPP	Cold Filter Plugging Point
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EN	European Norm
HC	Unburned Hydrocarbons
NO_x	Nitrogen Oxides
TS	Turkish Standard
US	United States

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Conflicts of Interest: The authors declare no conflict of interest.

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