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# Combustion and Emission Analysis of Cyclamen Persicum and Fritillariapersica Biodiesel

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## 1. Abstract

The purpose of this report is to investigate two new generations of second-generation biodiesel that have better advantages over the rest of biodiesels and diesel fuel. The performance and emission of the Cyclamen persicum and Fritillariapersica biodiesel were assessed in the single-engine diesel and blends of 5%, 20%, 50%, 100%, and standard diesel fuel separately. The results could show that the use of biodiesels produced lower smoke opacity (up to 89%), and higher brake specific fuel consumption up to 13-15%. Co, NOx, SO2 were decreased remarkably for the most biodiesels compared to diesel fuel. Exhaust gas temperature was so closed to the diesel fuel. The results for torque and engine power were better than diesel fuel with 5% blends. The results showed that the Cyclamen persicumbiodiesel not only had better results than diesel fuel but also had the potential to significantly reduce pollution. Also, the selected fuelshave low production cost and the ability to grow in dry and humid water and are not the same as the rest of the second generation in a specific region and have the capability of spontaneous growth and low cost of production and maintenance on an industrial scale.

**2. Keyword:** Biodiesel; Diesel engine; Cyclamen persicum; Fritillariapersica; Exhaust emissions

## 3. Introduction

The copious energy demand of the developed industrial world of today and limited sources of fossil fuels as common primary carriers of energy has led to a dilemma among societies. The contribution of fossil fuels in environmental degradation and global warming is so vast that intransigent standards of application have been regulated by governments for these fuels. Increasing prices of fossil fuel, on the other hand, is one of the other reasons of energy crisis in the world [1-3].

Interchangeability of biodiesels with fossil fuels is regardable due to their premiere properties compared with the diesel fuel. Biodegradability, trace amounts of sulphur and no toxicity is among other bright points of this biofuel. The use of biodiesels can abate the production of pollutants to a great extent as well as lessening the level of carcinogenic compounds [4, 5].

Three generations of biodiesels, according to their production sources, are considered to be a potential replacement to conventional diesel fuel. These sources mainly include edible vegetable oils as first generation and non-edible vegetable oils to be the second generation. Animal fats, algaes and waste cooking oils, on the other hand, are classified as the third generation of biodiesels. Introduction of the first generation of biodiesels to fuels arena drew an abundant attention to itself. But as they were produced from edible crops, which are vital in human dietary, overuse of this generation would result in a fuel-versus-food debate alongside of needing extensive areas of arable land. This competition will lead to higher prices of both edible oils and biodiesels. Cold flow properties is another problem that anent first generation of biodiesels [6-9]. Some disadvantages of the third generation of biodiesels are included: harder transesterification process of fat oils due to their greater amounts of saturated fatty acids, biosafety problems as a result of using fats from infected animals, higher cultivation prices and frequent harvesting of algaes as compared with the first and second generation and also advanced technology requirements of algal harvesting as well as higher energy in let that increases the total cost of production. Oils produced from algal sources face a greater risk of oxidation when exposed to air due totheir

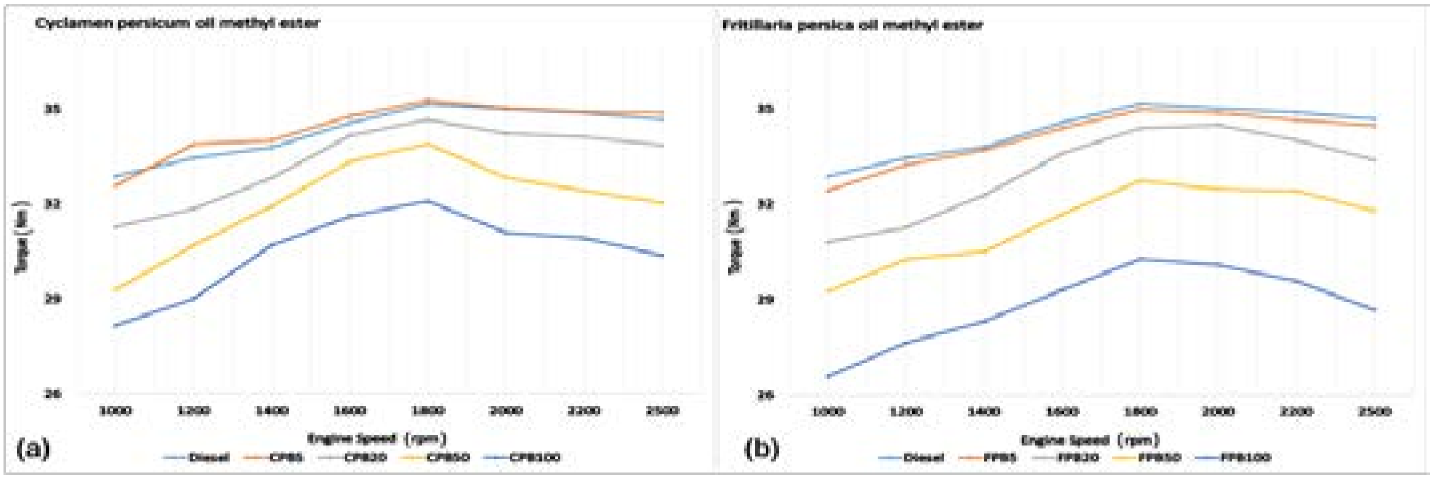


**Figure 1:** The variation of torque at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel.

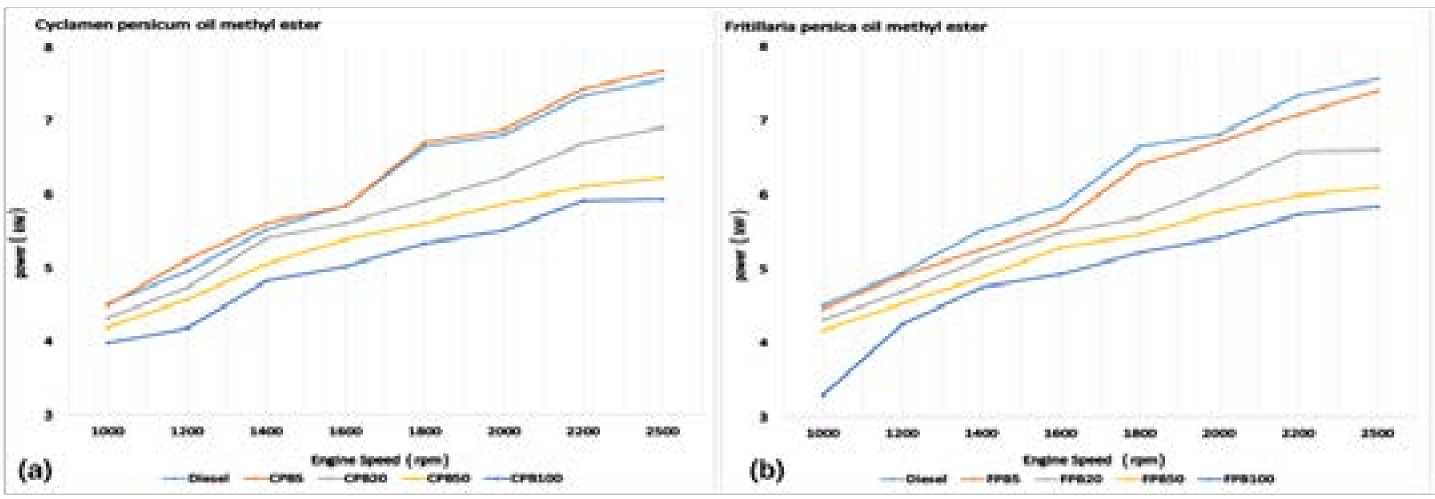


**Figure 2:** The variation of power at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel.

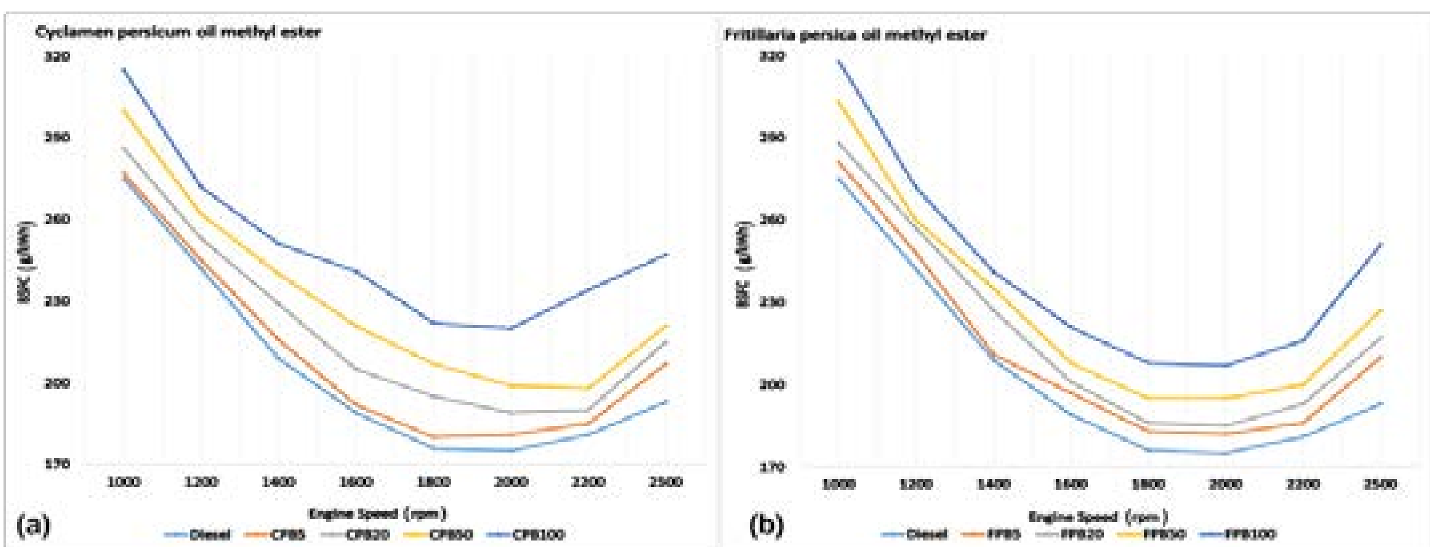


**Figure 3:** The variation of BSFC at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel.

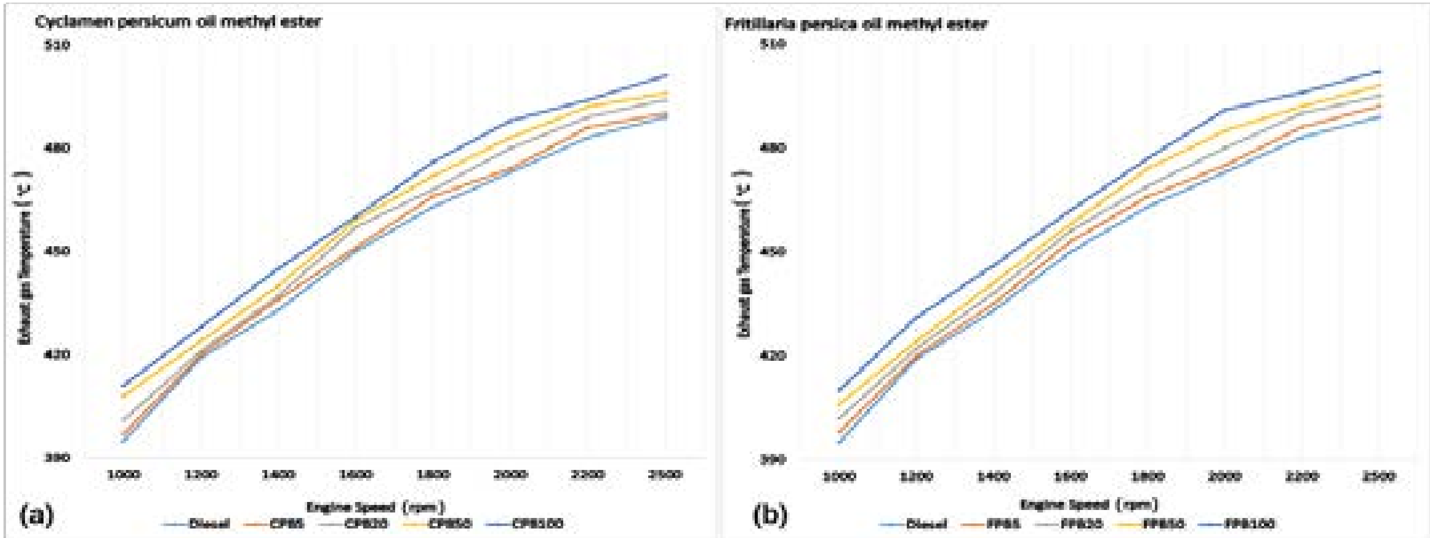


**Figure 4:** The variation of EGT at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel.

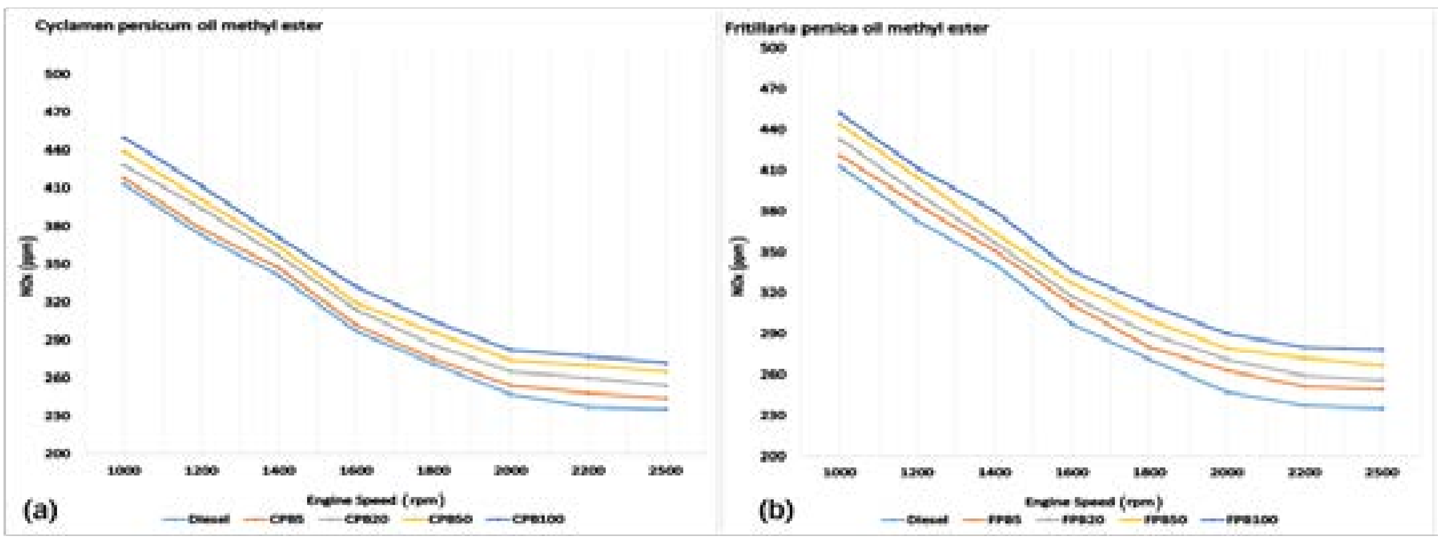


**Figure 5:** The variation of NOx emission at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel.

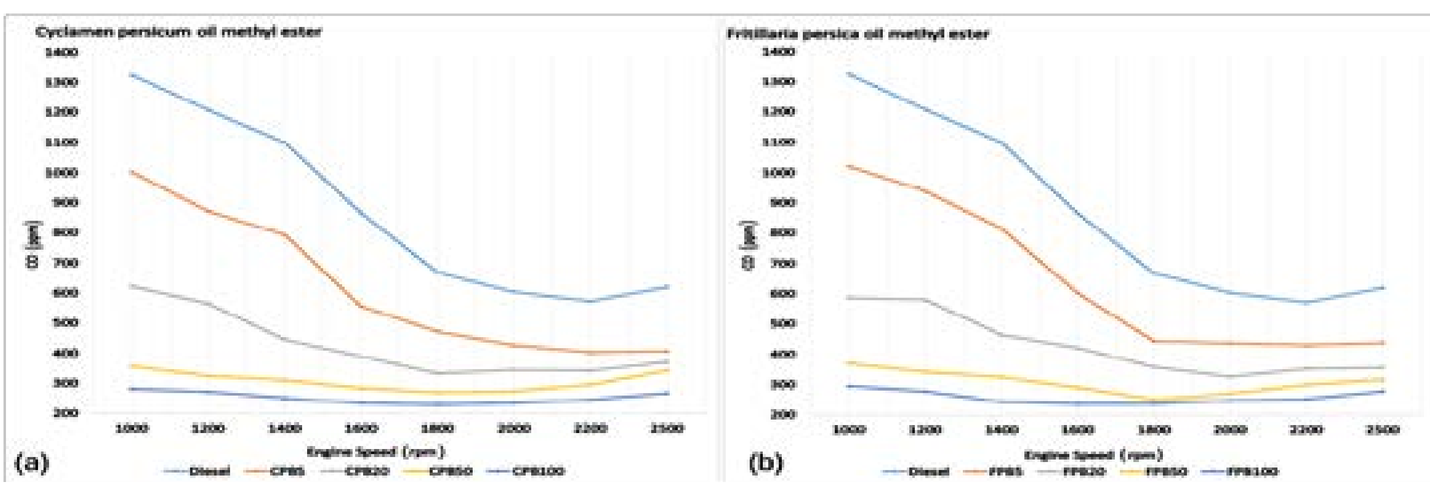


**Figure 6:** The variation of CO emission at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel.

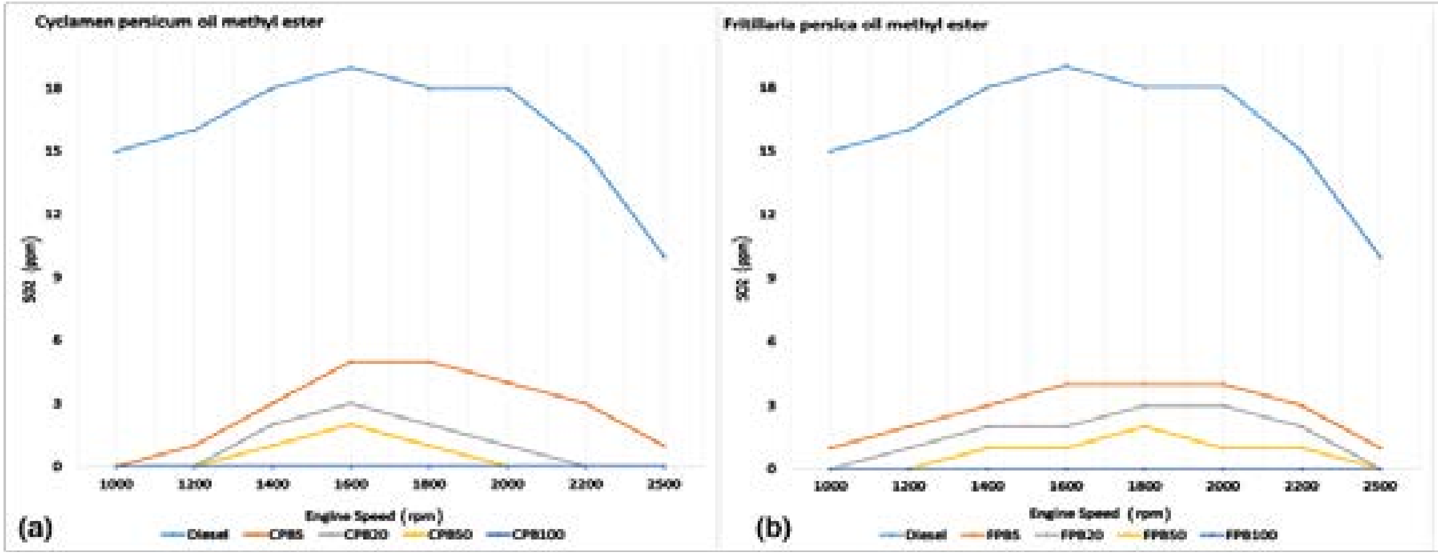


**Figure 7:** The variation of $SO_2$ emissions at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel.

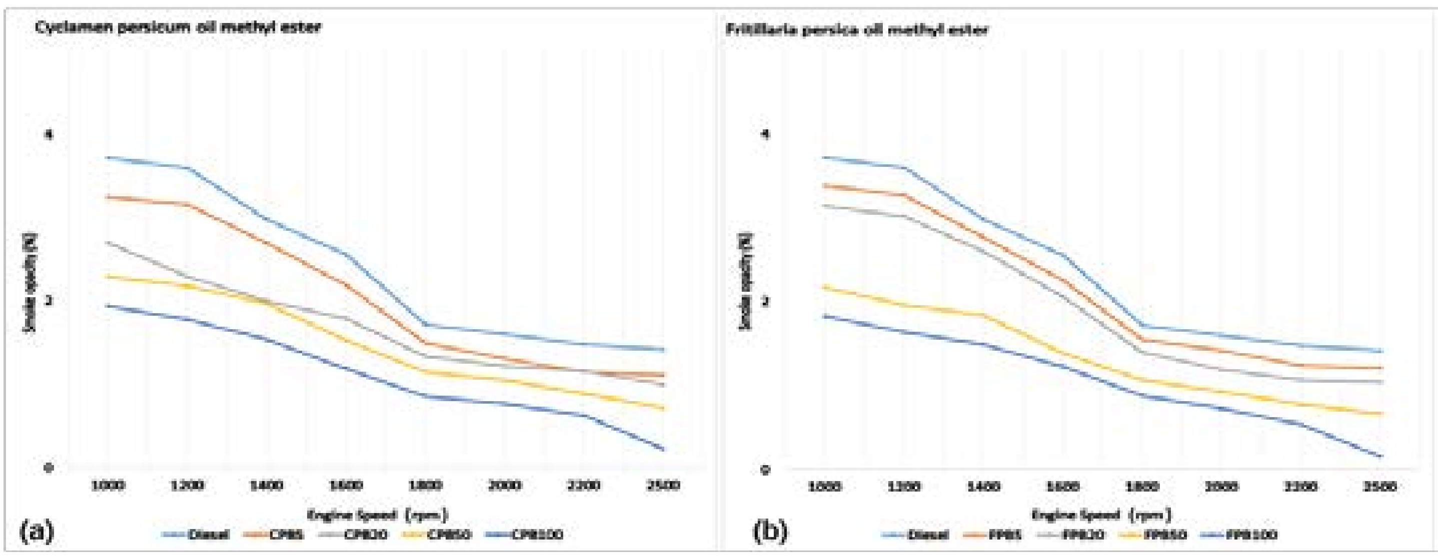


**Figure 8:** The variation of smoke opacity at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel.

higher content of PUFAs [8-12].The exact amount of biodiesel produced from a certain quantity of algal source is unpredictable and inaccurate as well as being unstable with poor performance characteristics compared to its other rivals. Thus production of biodiesel from algaes without consideration of other production options is not economically feasible [13-17]. Presence of unwanted solid impurities in waste oils and having high water content, as well as free fatty acids, are other problems relating to third generation of biodiesels which cause hydrolysis, saponification and lower biodiesel yield and high catalyst consumption accordingly [18, 19].

With the drawbacks of first and third generation, the second generation of biodiesel seems to be a promising alternative to fossil fuel. As this generation is produced from non-edible sources, it eliminates the dependency on food-feed products. This type of biodiesels also can be cultivated in non-arable waste lands at a much lower price compared to the first generation. Second generation of biodiesel has a wide range of feedstock's that are more environmentally friendly as their cultivation reduces the amount of greenhouse gas such as $CO_2$. Higher conversion and biodiesel yield are achieved through second generation of biodiesels as compared to other generations. Production of useful byproducts and better engine performances of some types are also another advantages among so many benefits of using second generation biodiesels [20-22].

**Table 1:** Physicochemical properties of biodiesel blends and diesel.

| Property | A S T M method | Diesel | CPB5 | CPB20 | CPB50 | CPB100 | FPB5 | FPB20 | FPB50 | FPB100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Kinematic viscosity at 40 °C | D445 | 2.56 | 2.60 | 2.65 | 3.08 | 3.81 | 2.73 | 2.83 | 3.11 | 4.01 |
| Cetane number | D613 | 47 | 51 | 56 | 59 | 62 | 50 | 55 | 57 | 59 |
| Heating value $KJ.kg^{-1}$ | D2015 | 44820 | 44630 | 44510 | 43100 | 42170 | 44110 | 43890 | 42780 | 41990 |

**Table 2:** Specifications of the engine.

| | |
|---|---|
| Type | Rainbow–186 Diesel |
| Cylinder Number | 1 |
| Cooling System | Air Cooling |
| Compression Ratio | 18:1 |
| Injection System | Direct Injection |
| Maximum Power | 10 HP |
| Maximum Engine Speed | 3600 rpm |
| Mean Effective Pressure (Mep) | 561.6 Kpa |
| Medium Piston Speed | 7.0 m/sn (at 3000 rpm) |
| Dynamometer model | BT-140 |

Emissions produced by biodiesels usually includecarbon dioxide ($CO_2$), oxides of nitrogen (NOx), carbon monoxide (CO), and particulate matter (PM) [5, 23]. Three different non-edible oils from jatropha, karanja, and polanga were used as feedstock for production of biodiesel and their blends of B20 and B50 in a study by Sahoo et al. Their investigations were based on power, BSFC, and smoke emission in different engine speeds. The results implied that the B50 biodiesel blend ofjatropha had the highest increase in power at all rated engine speeds. BSFC of blend samples containing higher amounts of biodiesel showed higher values but were decreased with an increase in engine speed. On the other hand, smoke emission was lower in all biodiesels and their blends in comparison with pure diesel fuel. They also reported a reduction in smoke production in reduced engine speeds [24]. Ozturk et al used the mixture of the canola oil–hazelnut soapstock biodiesels and diesel fuel No. 2 in their study. The addition of biodiesel resulted in the reduction rates of ignition delays, injection, and heat release. Also, they indicated the combustion and injection durations enhanced. The oxygen content of B5 contributed to an increased combustion, which led to higher NOx emission and less CO and smoke formation. However higher viscosity, surface tension, and density of B10 reduced combustion. Diesel No.2 had the same results of $CO^2$ emission [25]. The feasibility of biodiesel and application of direct injection diesel engine was investigated by Ashraful et al. higher brake thermal efficiency was achieved with the diesel fuel as compared to the biodiesels blending. The calophylluminophyllum biodiesel blending displayed 6.35% inferior amount of the brake specific carbon monoxide. The brake specific hydrocarbon emission was decreased around 7.93%with the blends of palm biodiesel. Also the calophyllum inophyllum biodiesel blends reduced this emission around 9.5%. Enhancement in NOx emission to approximately 4.84% and 0.29% was observed in calophyllum inophyllum and palm biodiesel blends as compared to the diesel fuels. Both biodiesel blends decreased the amount of smoke intensity in B10 by around 27.5% in comparison to the diesel fuel [26]. Cashew nut shell oil is another non-edible feedstock that was used by Devarajan and colleagues for their study on the effects of adding phenol to biodiesels on emission and performance characteristics. Their research claimed positive results about emission reduction by making combinations of phenol and biodiesels. Smoke and unburned hydrocarbons reduced to an extent of 2.1% and 2.6% respectively. NOx production was reduced by 5.1% while CO emission had the highest reduction of 10.1% [27]. The non-edible feedstock was used in the study of Sanjid et al. The brake specific fuel consumption (BSFC) of the kapok-moringa mixed biodiesel blends increased around 6-9%, as well as the brake power declined, nearly around 5-7% compared to diesel fuels. The kapok-moringa mixed biodiesels had higher CO2 emissions and NO than diesel fuel around 1-3% and 14-17%, but they had lower CO and HC emission around 16-31% and 23-38% in comparison with the diesel fuel [28]. B10 blend of Rapeseed oil biodiesel in the study of Miri et al. showed the highest amount of power and torque at 1800 and 2600 rpm. At 1800 rpm, the lowest specific fuel consumption was achieved by B10. Results could show that the CO and NOx emissions reached their highest amount at 1800 rpm for B20. B10, on the other hand, had the minimum CO and NOx emissions at 3000 rpm. With the enhancement of biodiesel blends, torque and power at 3000 rpm were declined [29]. In another study, Nalgundwar et al. worked on the blends of palm and jatropha as biodiesel. An increase in brake power was observed during the use of B10 as well as the reduction for the BSFC. Results for the B40 affected brake thermal efficiency and increased by around 15%. By using biodiesel blends the CO emissions production was reduced. B5 and B10 blends had higher NOx emissions around 5.3% and 9.2% compared to diesel fuel [30]. A recent research by Uyumaz et al studied the performance and emission of the mustard oil biodiesel. A reduction of 6.8% for thermal efficiency in B10 was shown compared to diesel fuel. Also, the BSFC was superior to diesel fuel to approximately 4.8%. The cylinder pressure had no significant difference between biodiesel and diesel fuel. The results indicated a noticeable reduction in smoke and CO emissions whilst NOx production for biodiesel blends was increased in comparison with the diesel fuel [31].

In this study we worked on two new species of non-edible vegetable oils. Cyclamen persicum and Fritillariapersica seed oil were used for biodiesel production. Both oils have high resistance to harsh climates. The purpose of selecting these two new types of biodiesel from the second generation is to cover the disadvantages of the first and third generation biodiesel and to survey the performance and emission specifications of these two new species in a diesel engine. Both types of biodiesel are capable of production on an industrial scale and spontaneous growth and do not require high maintenance costs. Alsoa comparison between samples and an assessment of better biodiesel with better specifications was conducted in the present work.

## 4 Materials and Methods

### 4.1. Preparation of Fuels and Analyzes

The crude cyclamen persicum and fritillariapersica seed oil was prepared. The transesterification procedure was employed to produce biodiesels. Oils were blended with methanol by 5:1 molar ratio and 0.3% w/v KOH as the catalyst. This procedure was done at 58-60 ˚C for 2 h. The separation procedure was done for 12 h. cyclamen persicum oil methyl ester and fritillariapersica oil methyl esters were blended with diesel (5, 10, 20, and 100 percent). They were included 5%cyclamen persicum biodiesel (CPB5), 20% of cyclamen persicum biodiesel (CPB20), 50% of cyclamen persicum biodiesel (CPB50), 100% of cyclamen persicum biodiesel (CPB100), 5% of fritillariapersica biodiesel (FPB5), 20% of fritillariapersica biodiesel (FPB20), 50% of fritillariapersica biodiesel(FPB50), 100% of fritillariapersica biodiesel (FPB100). The properties of the fuels are presented in (Table 1).

The test was performed in the diesel engine with a single cylinder. The characteristics of the engine were presented in (Table 2). The Exhaust gasses and smoke opacity were measured by the DRAGER MSI COMPACT 150 and the smoke-meter SUN ASA 200. The dynamometer model was BT-140 model. Nine different fuels were employed and the test was begun by the pure diesel. The emission and performance were performed at full load and variable engine speed situations for fuels.

## 5. Results and Discussion

### 5.1. Engine Torque

(Figure 1) shows the engine torque for diesel and biodiesel. Both biodiesels displayed that the engine torque enhanced to the maximum point (1800 rpm) with the growth of engine speed. Then, the torque of biodiesels decreased with the increase of the engine speed (between 1800 and 2500). Both biodiesels could show that the increase of the CPB and FPB in the blends caused the decrease of the torque results. Comparing between two biodiesels could show that CPB had higher torque compared to the FPB in all blends since the CPB blends had the higher heating value and lower viscosity compared to FPB blends. The heating value and the viscosity are reasons for decreasing the torque results during the increase of biodiesel in blends. The viscosity of the fuel raises the amount of the fuel that should be filled in the oil pump declines and the volumetric efficiency of the engine stays lower, therefore resulting in the torque reductions.

At 1000 rpm, the minimum of the torque was shown by the CPB100 and FPB100 compared to other biodiesel blends and diesel fuel. Also, the torque of FPB100 was lower than the CPB100 to approximately 6 %. CPB5 and FPB5 had the highest torque compared to other biodiesel blends and it was close to the diesel fuel. Between 1200 to 1800 rpm, the CPB5 had the higher torque compared to the diesel fuel (around 2%) and FPB5 was so closed to the diesel fuel (almost 1%). Oxygen content and calorific value CPB5 and FPB5 may be the reason for complete combustion and enhancing the torque. At 2500, the minimum of the torque was shown by the CPB100 and FPB100 and they were lower than diesel fuel around 13 and 17%. The lower vapourization and cylinder vacuum caused the air-fuel ratio to stay richer and bring about incomplete combustion at low speed of an engine, so it can decline the torque. Also, at the high speed of the engine, the amount of fuel provided with the pump stands lower due to the high viscosity.

### 5.2. Engine Power

The engine power for both biodiesel bends and diesel fuel is shown in (Figure 2). During the increase of the engine speed, the power of biodiesel blends and diesel fuel was enhanced. Both biodiesels could display that the increase of the CPB and FPB in the blends caused the decrease of the power results except CPB5. At 1000 rpm, the lowest engine power was shown by the CPB100 and FPB100 compared to other biodiesel blends and diesel fuel. However, the engine power of the CPB100 was higher than FPB100 around 1.5%. The CPB100 and FPB100 had higher viscosity and lower heating value compared to other fuels, so the combustion of them was completed less efficiently than others. At 2500 rpm, CPB5 and FPB5 had the highest engine power compared to other biodiesel blends and they had difference merely (around 2% higher and 3% lower with diesel fuel). At 1000 rpm, CPB5 and FPB5 had (1% higher and 2% lower) difference with diesel fuel.

### 5.3. Brake Specific Fuel Consumption

The BSFC is shown by (Figure 3) for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel. At 1000 rpm, the highest BSFC was gained by the CPB100 and FPB100 compared to other fuels. Besides, the FPB100 had a higher BSFC compared to the CPB100 around 1%. All biodiesel and diesel fuel were experienced a reduction between 1000 and 1800 rpm and the minimum BSFC was gained at 2000 rpm for all biodiesel. The BSFC of the CPB5 and FPB5 was so closed to the diesel fuel. At 1800rpm, the CPB5 and FPB5 were shown the lowest BSFC and the difference was only 3 and 4% with diesel fuel. At this engine speedthe BSFC was around 181 and 182 g/kWh for CPB5 and FPB5 and the diesel fuel was around 175. Calorific value, viscosity, and oxygen content are some of the important factors which affect the BSFC.

### 5.4. Exhaust Gas Temperature (EGT)

The EGT was shown by (Figure 4) for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel. The minimum of the EGT was shown at 1000 rpm for all biodiesel and diesel fuel. At this engine speed, the diesel fuel had the minimum EGT compared to other biodiesel blends and the EGT of CPB5 and FPB5 was closed to the diesel fuel and the difference was only around 1.5 and 1%. Also, the difference of EGT between CPB100 and FPB100 with diesel fuel were around 4%. The reason CPB100 and FPB100 have higher EGT than the others is because the biodiesel commonly contains some constituents having greater boiling points and they are not sufficiently evaporated over the combustion phase and continue to burn in the late combustion phase. It is caused by the upper exhaust temperature and lower thermal efficiency. During the increase of the engine speed, the EGT increased for all biodiesels and diesel fuel. The maximum EGT was gained at 2500 rpm for all fuels. The CPB100 and FPB100 had the maximum of EGT at this engine speed compared to other fuels. On the other hand, diesel fuel, CPB5, and FPB5 had the minimum of the EGT. The difference between diesel fuel and CPB5 and FPB5 were around 3%. Longer ignition delay and lower cetane number can affect the EGT and show the difference between all fuels at this engine speed.

### 5.5. NOx Emission

The amount of NOx emission is shown by (Figure 5) for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel. The NOx formation highly relies on the combustion duration, volumetric efficiency, and temperature rising from high activation energy required for the reactions involved. It was happed because of the increase in gas flow motion and volumetric efficiency in the engine cylinder under upper engine speeds, yielding shorter ignition delay and quicker mixing between air and fuel. The reaction time of the engine cycle was reduced and the residence time of the gas temperature in the cylinder was shortened. This caused lower NOx emissions under high engine speeds. Results showed that the increase of the biodiesels in blends caused the increase of the NOx formation because of the excess oxygen. At 1000 rpm the maximum amount of NOx emission was showed by the CPB100 and FPB100. On the other hand, the minimum of NOx was displayed by the diesel fuel, CPB5, and FPB5. The NOx emission of diesel fuel was lower than CPB5 and FPB5 around 2 and 3%. At 2500 rpm, the lowest amount of NOx emission was shown by all biodiesel blends and diesel fuel. At this engine speed, the diesel fuel was only 4 and 6% lower than CPB5 and FPB5. However, it was lower than CPB100 and FPB100 almost 14 and 16%.

### 5.6. CO Emissions

The CO emission was shown by (Figure 6) for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel. The general trend for CO emission showed a reduction during the increase of engine speed for all fuels. At 1000 rpm, the minimum of CO emission was gained by the CPB100 and FPB100 and they were lower around 79 and 77% than diesel fuel. CPB5 and FPB5 were lower than diesel fuel around 15 and 12%. At 2500 rpm, all fuels showed a huge reduction of CO emission and the minimum results were shown by the CPB100 and FPB100.

The difference between CPB5, FPB5, and diesel fuel was around 34 and 30%. The presence of oxygen content in biodiesels has caused the reduction of CO emission. The better complete combustion caused by the increased oxygen content in the flame coming from the biodiesel molecules can be indicated as the foremost reason in the decrease of CO emissions.

### 5.7. $SO_2$ Emissions

(Figure 7) shows$SO_2$emissions at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel. At 1000 rpm, the maximum of $SO_2$was shown by the diesel fuel and it was higher than biodiesel blends around 98-100%. CPB5 and FPB5 could show a significant $SO_2$reduction compared to diesel fuel (around 98-100%). At 2500 rpm, CPB100 and FPB100 showed no $SO_2$emission as the pure biodiesel has no sulphur content and CPB5 and FPB5 had lowest SO2reduction.

### 5.8. Smoke Opacity

The smoke opacity is shown by (Figure 8) at the full loaded engine for the cyclamen persicum oil methyl ester and fritillariapersica oil methyl ester blends and diesel. During the increase of engine speed, the smoke opacity was decreased for all fuels. At 1000 rpm, the maximum smoke opacity was gained by the diesel fuel compared to biodiesel blends. CPB100 and FPB100 were shown the lowest amount of smoke opacity and they were lower than diesel fuel around 48 and 51%. CPB5 and FPB5 also showed the decrease of smoke opacity around 13 and 10% compared to diesel fuel. At 2500 rpm, the diesel fuel was higher than CPB5, FPB5, CPB100, and FPB100 around 13, 15, 83, and 89%, respectively. The increase of oxygen content in fuel blends is caused by the higher fractions of the fuel carbon is converted to CO in the rich premixed area instead of soot formation. Also, those fuels with longer ignition delay via keeping the aromatic content constant reveal lower particulate emissions and greater NOx emission at high loads.

## 6. Conclusion

Biodiesel has many advantages over diesel fuel and can be a good alternative to diesel fuel. The present report uses two new types of second-generation biodiesel fuels. The second generation of biodiesel has many advantages such as growing in wastelands and needing less farmland, not affecting the human supply, useful by-products and being more efficient and environmentally friendly. The purpose of this article is to find fuel that does not have first and third generation problems and results in better diesel fuel as well as growth potential in different weather conditions. Results could show that the torque of CPB5 was approximately better than diesel fuel. Also, the torque of CPB20 and FPB20 had slight difference with diesel fuel. The results of the power for CPB5 and FPB5 were better than diesel fuel. The BSFC of the CPB5 and FPB5 was so closed to the diesel fuel and CPB100 and FPB100 had the maximum of the difference with diesel fuel between all fuels. EGT and NOx emission are related to one another and CPB5 and FPB5 had the minimum of the NOx emission between all biodiesels. CPB100 and FPB100 were shown the minimum of the CO and SO2 emission between all diesel fuels. The CPB100 and FPB100 had the lowest smoke opacity and had the highest difference with the diesel fuel because of the oxygen content and they decreased 83 and 89%. The CPB5 and FPB5 could show the best results between all tests and CPB5 had better results compared to other fuels. Both species have advantages in terms of economics, access, and growth in different regions. Both species can grow spontaneously and very cheap maintenance and the ability to grow in harsh weather conditions and can grow on an industrial scale around the world. Also, the results of engine and emission reductions compared to diesel and other biodiesel generation have been dramatic.

## 7. Acknowledgements

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**References**

1. Aydin H and Bayindir H, Performance and emission analysis of cottonseed oil methyl ester in a diesel engine. Renewable Energy. 2010; 35(3): p. 588-592.

2. Knothe G, Krahl J and Van Gerpen J, The biodiesel handbook. 2015.

3. Sakthivel R, Ramesh K, Purnachandran R and Mohamed Shameer P. A review on the properties, performance and emission aspects of the third generation biodiesels. Renewable and Sustainable Energy Reviews. 2018; 82: p. 2970-2992.

4. Borugadda VB, Paul AK, Chaudhari AJ, Kulkarni V, Sahoo N and Vaibhav VG Influence of Waste Cooking Oil Methyl Ester Biodiesel Blends on the Performance and Emissions of a Diesel Engine. Waste and biomass valorization, 2018. 9(2): p. 283-292.

5. Venu H, Subramani L, and Raju VD, Emission reduction in a DI diesel engine using exhaust gas recirculation (EGR) of palm biodiesel blended with TiO2 nano additives. Renewable Energy, 2019: 140: 245-263.

6. Brennan L and Owende P. Biofuels from microalgae—a review of

technologies for production, processing, and extractions of biofuels and co-products. Renewable and sustainable energy reviews. 2010; 14(2): p. 557-577.

7. Gui MM, Lee K, and Bhatia S, Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock. Energy. 2008; 33(11): p. 1646-1653.

8. Janaun J and Ellis N, Perspectives on biodiesel as a sustainable fuel. Renewable and Sustainable Energy Reviews. 2010; 14(4): p. 1312-1320.

9. Singh S and Singh D, Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review. Renewable and sustainable energy reviews. 2010; 14(1): p. 200-216.

10. Chisti Y, Biodiesel from microalgae. Biotechnology advances. 2007: 25(3): p. 294-306.

11. Demirbas A. Use of algae as biofuel sources. Energy conversion and management. 2010: 51(12): p. 2738-2749.

12. Ho SH, Chen CY, Lee DJ, Chang JS. Perspectives on microalgal CO2-emission mitigation systems—a review. Biotechnology advances. 2011; 29(2): p. 189-198.

13. Shalaby EA, Algal biomass and biodiesel production, in Biodiesel-Feedstocks and Processing Technologies. Intech Open. 2011.

14. Singh A, Nigam PS, and Murphy JD. Renewable fuels from algae: an answer to debatable land based fuels. Bioresource technology. 2011; 102(1): p. 10-16.

15. Slade R and Bauen A, Micro-algae cultivation for biofuels: cost, energy balance, environmental impacts and future prospects. Biomass and bioenergy. 2013; 53: p. 29-38.

16. Trivedi J, Aila M, Bangwal DP, Kaul S, Garg MO. Algae based biorefinery—how to make sense? Renewable and Sustainable Energy Reviews, 2015. 47: p. 295-307.

17. Ullah K, Ahmad M, Sofia, Sharma VK, Lu P, Harvey A, et al. Assessing the potential of algal biomass opportunities for bioenergy industry: a review. Fuel. 2015; 143: p. 414-423.

18. Meng X, Chen G and Wang Y, Biodiesel production from waste cooking oil via alkali catalyst and its engine test. Fuel processing technology. 2008; 89(9): p. 851-857.

19. Tan K, Lee K and Mohamed A, Potential of waste palm cooking oil for catalyst-free biodiesel production. Energy. 2011; 36(4): p. 2085-2088.

20. Ahmad A, Yasin NHM, Derek CJC, Lim JK. Microalgae as a sustainable energy source for biodiesel production: a review. Renewable and Sustainable Energy Reviews. 2011; 15(1): p. 584-593.

21. Bhuiya M, Rasul MG, Khan MMK, Ashwath N, Azad AK, Hazrat MA. Second generation biodiesel: potential alternative to-edible oil-derived biodiesel. Energy Procedia. 2014; 61: p. 1969-1972.

22. Naik SN, Vaibhav VG, Prasant KR, Ajay KD. Production of first and second generation biofuels: a comprehensive review. Renewable and sustainable energy reviews. 2010; 14(2): p. 578-597.

23. Lapuerta M, Armas O and Fernandez J. Biodiesel engine performance and emissions in low temperature combustion. Prog Energy Combust Sci. 2008; 34: p. 198-223.

24. Sahool PK, Das LM, Babu MKG, Arora P, Sing Vp, KUmar NR, et al. Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine. Fuel. 2009; 88(9): p. 1698-1707.

25. Öztürk E. Performance, emissions, combustion and injection characteristics of a diesel engine fuelled with canola oil–hazelnut soapstock biodiesel mixture. Fuel Processing Technology. 2015; 129: p. 183-191.

26. Ashraful AM, Masjuki HH, Kalam MA, Rashedul HK, Habibullah M, Rashed MM, et al. Impact of edible and non-edible biodiesel fuel properties and engine operation condition on the performance and emission characteristics of unmodified DI diesel engine. Biofuels. 2016; 7(3): p. 219-232.

27. Devarajan Y, Jayabal RK, Ragupathy D and Venu H. Emissions analysis on second generation biodiesel. Frontiers of Environmental Science & Engineering. 2017; 11(1): p. 3.

28. Sanjid A, Kalam AMd, Masjuki HH, Varman M, Zulkifli NWBM, Abedin MdJPerformance and emission of multi-cylinder diesel engine using biodiesel blends obtained from mixed inedible feedstocks. Journal of cleaner production, 2016; 112: p. 4114-4122.

29. Miri SMR, Seyedi SRM and Ghobadian B. Effects of biodiesel fuel synthesized from non-edible rapeseed oil on performance and emission variables of diesel engines. Journal of cleaner production. 2017; 142: p. 3798-3808.

30. Nalgundwar, A., B. Paul, and S.K. Sharma. Comparison of performance and emissions characteristics of DI CI engine fueled with dual biodiesel

blends of palm and jatropha. Fuel. 2016; 173: p. 172-179.

31. Uyumaz A. Combustion, performance and emission characteristics of a DI diesel engine fueled with mustard oil biodiesel fuel blends at different engine loads. Fuel. 2018; 212: p. 256-267.