Section A-Research paper

Performance Investigation of the Single Cylinder Compression Ignition Engine employing Turmeric Leaf (Curcuma Longa) Oil Biodiesel at Varying Operating Conditions

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Abstract:

Rising price, increasing demand and limited resources of petroleum products requires an alternative fuel produced from eco-friendly resources. Biodiesel produced from various organic resources like vegetable oils, non-edible oils, animal fats are increasing interest for the researchers as an alternative to the diesel. The present work consists of performance analysis of single cylinder diesel engine employing turmeric leaf oil (curcuma longa) based biodiesel with three different biodiesel blends viz. B10, B20 and B30 and its comparison with the commercial diesel. For comparative analysis, the engine was operated at varying engine loads, compression ratio and fuel injection pressures using diesel as well as biodiesel blends. The engine records highest brake thermal efficiency of 24.84% and lowest BSFC of 0.28 kg/kWh at 600 bar injection pressure, compression ratio of 18 and at full engine load with diesel fuel. At same operating conditions, the BTE and BSFC recorded are 23.84% and 0.29 kg/kWh for B10, 23.38% and 0.32 kg/kWh for B20 and 23.22% and 0.34 kg/kWh respectively. All biodiesel blends exhibit comparable performance to the diesel in terms of BTE and BSFC at all engine operating conditions. The B10 blend shows better performance amongst all biodiesel blends.

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Keywords: *Turmeric leaf oil, biodiesel, performance parameters, brake thermal efficiency, brake specific fuel consumption, injection pressure, compression ratio.*

Abbreviations

NO_x	Oxides of Nitrogen	CO	Carbon Monoxide
CO_2	Carbon Dioxide	SOx	Oxides of Sulphur
HC	Hydrocarbons	PM	Particulate Matter
ICE	Internal Combustion Engine	BTE	Brake Thermal Efficiency in %
BSFC	Brake Specific Fuel Consumption, kg/kWh	EGT	Exhaust Gas Temperature, ^{0}C
Bx	Blend of biodiesel containing x% biodiesel and (100-x)% diesel	BP	Brake Power, kW
CI	Compression Ignition	4S	Four Stroke
VCR	Variable Compression Ratio	BMEP	Brake Mean Effective Pressure, bar
InP	Injection Pressure, bar	ITE	Indicated Thermal Efficiency, %
IMEP	Indicated Mean Effective Pressure, bar	CR	Compression Ratio
ASTM	American Society for Testing and Materials	IP	Indicated Power, kW
bTDC	Before Top Dead Center		

1. Introduction:

Owing to the rapid urbanization, industrialization and population hike, the demand for petroleum products like petrol and diesel is increasing day by day [Sayyed2021, Dharsini2022, Awogbemi2021, Ayhan2020]. The limited resources for the fossil fuel are not sufficient to cater the increasing demand is leading to hike in petrol and diesel prices [Dharsini2022]. Furthermore, the harmful gases like oxides of nitrogen (NOx), carbon monoxide (CO), carbon dioxide (CO2), oxides of sulphur (SOx) and particulate matter (PM) emitted from the combustion of fossil fuels causes serious issues like global warming, climate change etc [Dharsini,2022; Awogbemi,2021; Ellapan,2021; Elkelawy,2020; Karthikeyan,2020; Murugapoopathi,2020; Gozmensali,2020]. In addition to this, the strict emissions norms led by various regulatory bodies on the emissions from the internal combustion engines (ICEs) necessitates the use of an environment friendly fuel produced form renewable sources in ICEs [Mourad,2021; Ayhan,2020; Murugapoopathi,2020; Gozmensali,2020].

Biodiesel which is produced from organic sources like edible and non-edible vegetable oils, animal fats, waste oil and microalgae has emerged as a promising alternative to the diesel [Miriam,2021, Gozmensali,2020]. Through significant research it is proven that the replacing diesel with biodiesel helps to reduce the pollution owing to low carbon content, non-toxic, bio-degradable properties of biodiesel [Miriam,2021]. High cetane number, presence of oxygen, minute amount of sulphur, higher flash point temperature, greater combustion efficiency and better lubricating properties of vegetable oils are the key features that promotes the use of the vegetable oil based biodiesel [Simsek,2020]. However, high amount of free fatty acids, high cloud and pour point, limited area of vegetable oil cultivation limits the use of biodiesel synthesized from edible and non-edible vegetable oils [Miriam,2021].

[Ansari2018] evaluated the performance of a diesel engine and analysed emissions using polanga based biodiesel (10%, 20%, 30% and 40% blends with diesel) and compared it with that of diesel. The study reported highest brake thermal efficiency (BTE) of 33.5% using 30% blend and lowest unburnt HC emissions (24 ppm) with 40% blend. The comparative analysis of sunan pecan based biodiesel (B5, B10, B15 and B20 blend) with diesel reported decrease in CO and HC emissions, increase in brake specific fuel consumption (BSFC), decrease in brake power (BP), torque and BTE with use of biodiesel [Ariani2017]. [Cheikh2016] experimented with waste cooking oil based biodiesel (B25, B50 and B100 blends) and compared the performance and emissions with that of diesel. [Dharsini2022] reported reduction in NOx, HC and CO emissions as well as increase in BTE with decrease in BSFC at full load with the use of novel biodiesel blends of methyl esters of pumpkin oil and neem oil with CeO_2/ZrO_2 nano composites. The experimental investigation of CI engine using Tamanu biodiesel (B10, B20, B30 and B40 blends) revealed that the use of Tamanu biodiesel reduced CO, NOx and HC emissions with improvement in the engine performance in comparison to commercial diesel fuel [Dinesh2016]. [Elkelawy2020] investigated the effect of addition of n-pentane additives (0.5%, 1% and 1.5%) into biodiesel prepared from scenedesmus obliquus algae on the performance and emission from the engine and compared it with the diesel and the biodiesel blends. The increase in BTE, reduction in BSFC, higher heat release rate with lowered HC and CO emissions were recorded in comparison to biodiesel blend and pure diesel. [Ellappan2021] analysed effect of diethyl ester addition to eucalyptus oil and diesel blend on the performance and emission from low heat rejection CI engine. It was concluded that diethyl ester additives significantly improved the performance with considerable reduction in NOx, CO and HC emissions. [Ghanbari2021] concluded that addition of alumina nanoparticles to the biodiesel and diesel blends with positive effect on the performance of the engine and reduces the harmful emissions significantly with little modifications in the engine design. [Ananthakumar2017] compared performance characteristics, combustion characteristics and emission characteristics of waste cooking oil biodiesel with pure diesel at varying operating conditions of load and compression ratio.

The study represents the performance evaluation of the single cylinder CI engine using various biodiesel blends (B10, B20 and B30) and its comparison with the pure diesel. The performance analysis includes brake specific fuel consumption, brake thermal efficiency and mechanical efficiency of the engine at various operating conditions.

2. Experimental Setup and Procedure:

2.1 Turmeric Leaf Oil (Curcuma Longa) as Biodiesel:

Significant research and development is been conducted by various researchers with biodiesel derived from edible oils like rapeseed, soybean, peanut, sunflower, coconut etc. However, use of these oils for the production of biodiesel may lead to the shortage of edible oil and price hike. Furthermore, non-edible oils produced from feedstock like neem, jatropha, karanja etc. are not cultivated separately on commercial scale. However, turmeric is commercially cultivated in India over a large area from years. India is the world's largest turmeric producer, and produces around 78% of the world's total turmeric production followed by China (8%) and Myanmar (4%) [Tamilnadu report]. Statistics of turmeric cultivation and production for FY2019-20 for top five turmeric producing states in India [indianspices.com] are tabulated in the table 1. During harvesting of turmeric, the roots (rhizomes) of turmeric plant are collected for further processing and remaining part containing leafs, petiole and psudostem is thrown. The turmeric leaf oil can be prepared from this waste biomass of the turmeric plant to prepare biodiesel without requiring separate land for cultivation. Large production, use of waste biomass and no requirement of separate cultivation makes turmeric leaf oil a best raw material for biodiesel production.

Table 1: Turmeric Cultivation and Production Statistics for FY2019-20

State	Area (ha)	Share (%)	Production (MT)	Share (%)
Telangana	55444	18.72	386596	32.80
Maharashtra	54248	18.32	218873	18.57
Karnataka	20740	7.00	132668	11.25
Tamilnadu	18432	6.22	96254	8.16
Andhra Pradesh	29717	10.03	71321	6.05
India (Total)	296181		1178750	

2.2 Biodiesel Blends:

For this study, biodiesel was prepared from turmeric leaf based vegetable oil using a twin stage separation method. Raw turmeric leaf oil was maintained at a temperature of 60-65^{0}C in an electric heating chamber. The heated oil was allowed to react with methanol (CH_3OH, 17% by vol.) and sulphuric acid (H_2SO_4, 5% by vol.) at the same temperature for about 60 min. Using a separation funnel, impurities in the oil like methanol was removed. After separation, the oil was again heated to 60-65^{0}C in heating chamber and reacted with CH_3OH (17% by vol.) and KOH (potassium hydroxide, 12% by vol.) for about 60 min. To remove methanol and glycerine from the oil, the oil was again kept in the separation funnel for about 11-12 hr. The turmeric oil free from impurities was then used to prepare various biodiesel blends. The blend was prepared by mixing pure diesel and biodiesel in a measured quantity using a mechanical stirring method (1460 rpm) for about 10 min. Three different biodiesel blends were prepared through blending biodiesel with commercially available diesel fuel (B10, B20 and B30. The detailed process of biodiesel preparation in depicted in the figure 1.

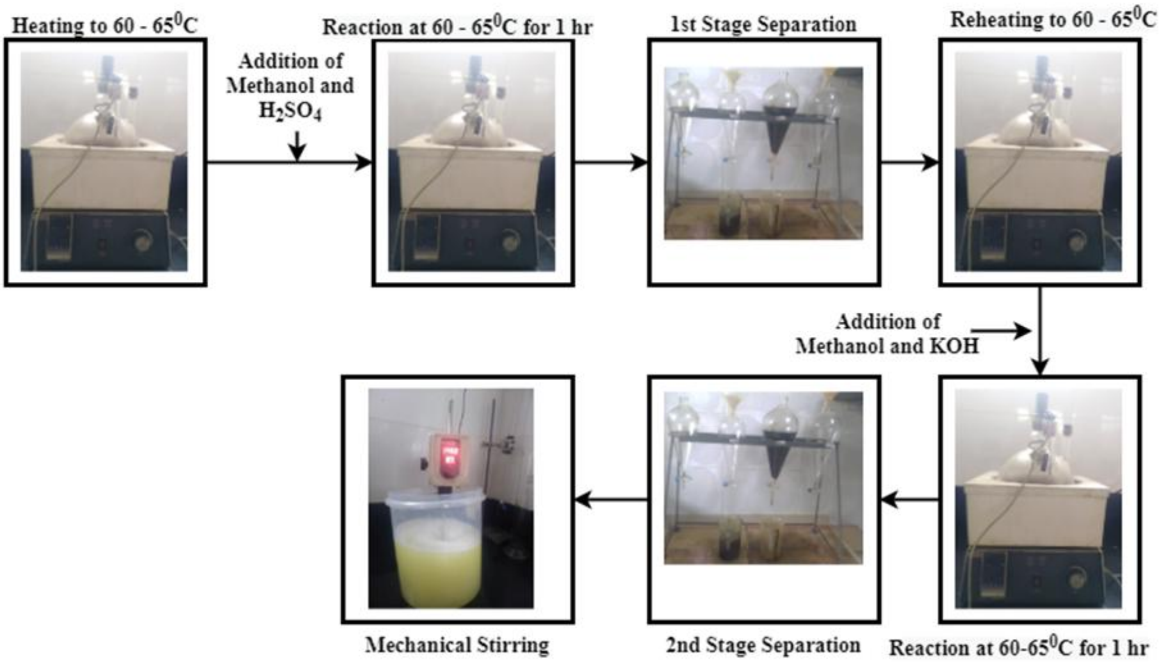


Figure 1: Biodiesel Blend Preparation Process

The various properties of these fuels like density, viscosity, calorific value, flash point and fire point etc. was measured by following ASTM standard test methods. Measured properties of all fuels and test method followed for the same are tabulated in the table 2.

Table 2: Thermo-physical Properties of Test Fuels

Property	**Diesel**	**B10**	**B20**	**B30**	**Test Method**	**Instrument Used**
Density, kg/m^3 (@ 25^0C)	816	836	839	843	ASTM - D287	Hydrometer
LCV, kJ/kg	42827	41794	41455	40819	ASTM - D4809	Bomb calorimeter
HCV, kJ/kg	45279	44246	43907	43270	ASTM - D4809	Bomb calorimeter
Flash Point, ^{0}C	53	76	83	92	ASTM-D93-58T	Pensky-Martens closed cup tester
Fire Point, ^{0}C	56	79	86	96	ASTM-D93-58T	Pensky-Martens closed cup tester
Kinematic Viscosity (@ 40^0C), kg/m-s	$1.73*10^{-3}$	$2.58*10^{-3}$	$2.76*10^{-3}$	$3.05*10^{-3}$	ASTM-D445	Calibrated glass capillary viscometer
Dynamic Viscosity (@ 40^0C), m^2/s	$2.09*10^{-6}$	$3.09*10^{-6}$	$3.31*10^{-6}$	$3.62*10^{-6}$	ASTM-D445	Calculated for kinematic viscosity

It can be seen that, with addition of more biodiesel in the blend, the density and viscosity of biodiesel blends increases as compared to the diesel due to presence of free fatty acids in the biodiesel. In addition to this, the calorific value of the biodiesel blends decreases with the rise in biodiesel proportion due to higher oxygen content of turmeric leaf oil.

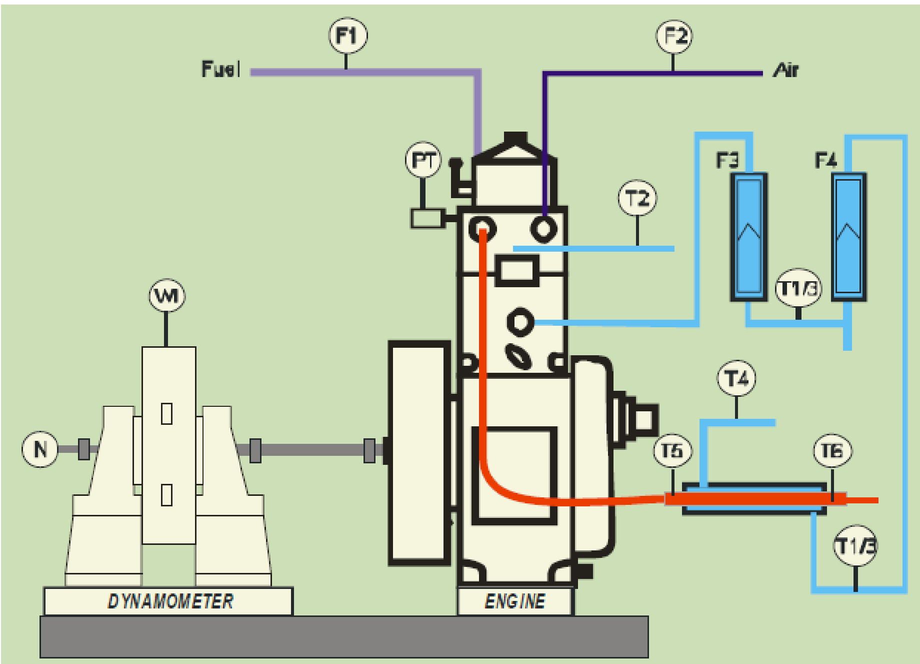
2.2 Experimental Setup:

The setup consists of a multi-fuel single cylinder, four-stroke (4S), water cooled, VCR (Variable Compression Ratio) research engine coupled to eddy current dynamometer. The setup can be operated on petrol as well as diesel mode. It has necessary provisions for the measurement of temperatures, fuel flow, air flow, engine load, pressure etc. The test setup is interfaced to the computer system through high speed data acquisition system. A 16-bit, multifunctional input output device, model USB: 6210 (NI Instruments, USA) capable of measuring 250 kilo samples per second was used as data acquisition system. Measurement of engine cooling water and calorimeter water flow was enabled by rotameter. The setup comprises of a panel box incorporating fuel measuring device, duel fuel tank, air box, manometer, transmitter employed for air and fuel measurement, piezo powering unit etc. The test setup facilitates measurement of various performance parameters like BP, BTE, brake mean effective pressure (BMEP), indicated power (IP), indicated thermal efficiency (ITE), indicated mean effective pressure (IMEP), heat balance parameters, combustion parameters etc. during the engine runtime. Technical specifications of the test engine are displayed in the Table 3. The pictorial view and schematic arrangement of the test setup is depicted in the figure 2.

Table 3: Technical Parameters of the Test Setup

Parameter	Description
Engine Make and Type	Kirloskar made, single cylinder, 4S, water cooled
Bore and Stroke	87.5 mm, 110 mm
Injection Timing	23^0 bTDC
Rated Capacity	3.5 kW at 1500 rpm (Diesel mode)
Compression Ratio Range	12-18
Dynamometer Type	Eddy Current Dynamometer
Temperature Sensor	PT100 (RTD) and Type-K thermocouple
Calorimeter	Pipe in pipe type
Data Acquisition System	16 bit with sampling rate of 250 kS/s (kilo samples/s)

(a)



(b)

Figure 2: Experimental Test Setup (a) Pictorial View, (b) Conceptual Diagram

2.3 Experimental Procedure:

The research work undertaken aims to investigate the effect of varying engine load, injection pressure and compression ratio on the performance of diesel engine using diesel and various biodiesel blends. To do so, the engine was operated at varying load (3 kg, 6 kg, 9 kg and 12 kg), varying injection pressures (400 bar, 500 bar and 600 bar) and varying compression ratio (16, 17 and 18). At the start of the test, the fuel tank, and fuel supply lines of the engine were cleaned to remove the residual fuel from the engine. The biodiesel blend to be tested was poured into the fuel tank and engine was operated for 10 minutes for steady operation. The required load on engine (kg) was computed for 25%, 50%, 75% and 100% loading conditions from the rated capacity of the engine. The various performance parameters required for the study like speed, torque, fuel consumption, BP, IP, BTE, BMEP, ITE, IMEP, temperatures were recorded through data acquisition system. The same procedure was repeated with 6 kg, 9 kg and 12 kg load. The engine was operated at all loads for each injection pressure and compression ratio. At the end of the test, the residual fuel in the fuel supply system was cleaned before filling the next combination of biodiesel for the test. The details of experimental tests are systemized in the table 4.

Table 4: Details of Experimental Tests

Test Fuel	**Load (kg) Levels**				**Injection Pressure (bar) Levels**			**Compression Ratio Levels**			**Number of Tests**
	1	**2**	**3**	**4**	**1**	**2**	**3**	**1**	**2**	**3**	
Diesel	3	6	9	12	400	500	600	16	17	18	36
B10	3	6	9	12	400	500	600	16	17	18	36
B20	3	6	9	12	400	500	600	16	17	18	36
B30	3	6	9	12	400	500	600	16	17	18	36

Results and Discussion:

Brake Thermal Efficiency:

Brake thermal efficiency of the engine accounts for the amount of total energy supplied to the engine converted to useful brake power of the engine. It is evaluated by measuring the brake power produced by the engine and calculating the chemical energy supplied to the engine in the form of fuel.

Effect of Engine Load on BTE:

BTE of the engine was evaluated at all engine loads, injection pressures and compression ratio. The variation of average BTE at various engine loads is depicted in the figure 3. The graph represents average BTE at each engine load (at each compression ratio and injection pressure). It is evident that, the performance of the engine is superior at higher engine loads and hence BTE of the engine increases with the engine load. At lower engine loads, the major share of the power produced in the engine (indicated power) is compensated for friction in the engine. On the other hand, at higher engine loads a small part of the indicated power is utilized to overcome friction and hence a major part of the indicated power is converted to brake power. In comparison to the diesel, all biodiesel blends have higher viscosity and lower calorific value which severely affects combustion and results in lower power output. As a result of this, the engine exhibits higher BTE with diesel fuel at all engine loads. BTE of the engine decreases with increase in the biodiesel percentage in the blend.

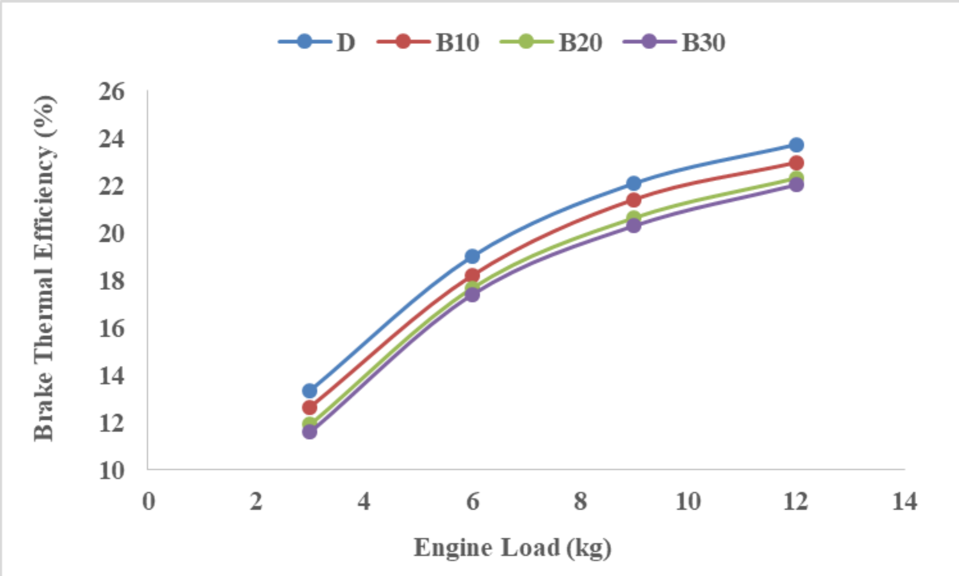


Figure 3: Effect of Engine Load on Brake Thermal Efficiency

The BTE of the engine is in the range of 11.60% to 13.35% at 3 kg load, 17.39% to 19.00% at 6 kg load, 20.30% to 22.10% at 9 kg load and 22.03% to 23.73% at full load condition for diesel, B10, B20 and B30 test fuels. At each loading condition, the BTE of the engine with diesel is higher than all biodiesel blends.

Effect of Injection Pressure on BTE:

To investigate the effect of injection pressure on the performance of the engine, the engine was operated at 400, 500 and 600 bar injection pressure at varying loading conditions and compression ratio. The effect of increasing injection pressure on the BTE of the engine at all engine loads and compression ratio is depicted in the figure 4. From figure 4 it is clear that, increasing fuel injection pressure positively affects the performance of the engine by increasing the BTE. Increasing the injection pressure enhances the atomization of the fuel and promotes better vaporization as a result of large surface to volume ratio of the fuel droplet. This results into complete combustion of the fuel at higher injection pressures. The atomization and vaporization of the fuel is affected by the density and viscosity of the fuel.

Owing to the high density and viscosity of the biodiesel, the BTE of the engine is higher for diesel engine as compared to biodiesel blends for a given injection pressure.

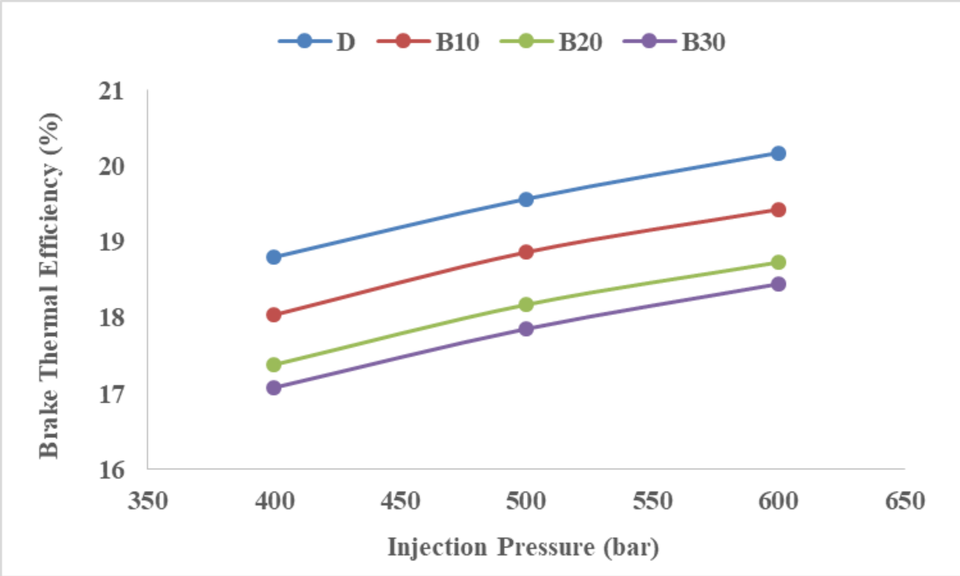


Figure 4: Effect of Injection Pressure on Brake Thermal Efficiency

Among all tests, the B30 blend shows lower average BTE of 18.45% at 400 bar injection pressure. On the other hand, the pure diesel records highest average BTE of 20.18% at injection pressure of 600 bar. Among all biodiesel blends, B10 blend exhibits highest thermal efficiency of 18.04%, 18.86% and 19.43% at 400, 500 and 600 bar injection pressure respectively.

Effect of Compression Ratio on BTE:

For a given engine load and injection pressure, the engine was operated at different compression ratio (16, 17 and 18) to study the influence of compression ratio on engine performance. Engine shows increase in the BTE with increase in compression ratio from 16 to 18 for all test fuels as depicted in the figure 5. At higher compression ratio, the pressure and temperature of compressed air is higher which results into complete combustion of fuel and coverts maximum chemical energy of fuel into useful work. With increased proportion of the biodiesel in the blend, the density and viscosity of the blend increases and calorific value decreases as displayed in the table 2. This affects combustion due to poor atomization of fuel and lower brake power because of lower calorific value. As a result of this, the BTE of the engine decreases with increase in the biodiesel content of the blend.

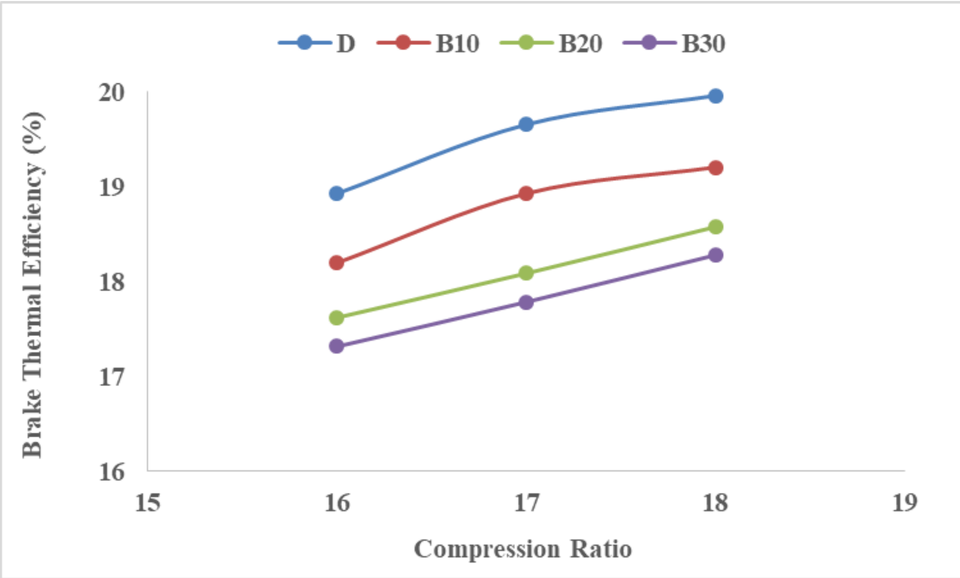


Figure 5: Effect of Compression Ratio on Brake Thermal Efficiency

The average BTE of the engine with diesel is 3.77%, 6.92% and 8.42% greater than B10, B20 and B30 blend respectively at compression ratio of 18. The engine records highest BTE of 24.84% (with diesel) while lowest BTE of 10.51% (with B30 blend).

Brake Specific Fuel Consumption:

BSFC measures amount of fuel consumed by the engine per unit time to produce unit brake power. It is calculated by measuring the fuel consumed by the engine and brake power produced by the engine.

Effect of Engine Load on BSFC:

The engine was operated at four different loading conditions for all cases of injection pressure and compression ratio to study effect of engine load on BSFC. Figure 6 displays variation of average BSFC at all injection pressure and compression ratio. It is perceptible from the figure that, increase in engine load reduces BSFC of the engine for all fuels. With increase in engine load, the fuel consumption of the engine increases in terms of kg/hr. However, due to higher mechanical efficiency at higher engine loads, the major part of indicated power is converted to the brake power. This reduces BSFC of the engine with increase in the engine load. The B30 records highest BSFC values at all loads in comparison to the other blends and pure diesel. The high density, high viscosity and lower calorific value of the biodiesel affects combustion and increases the BSFC.

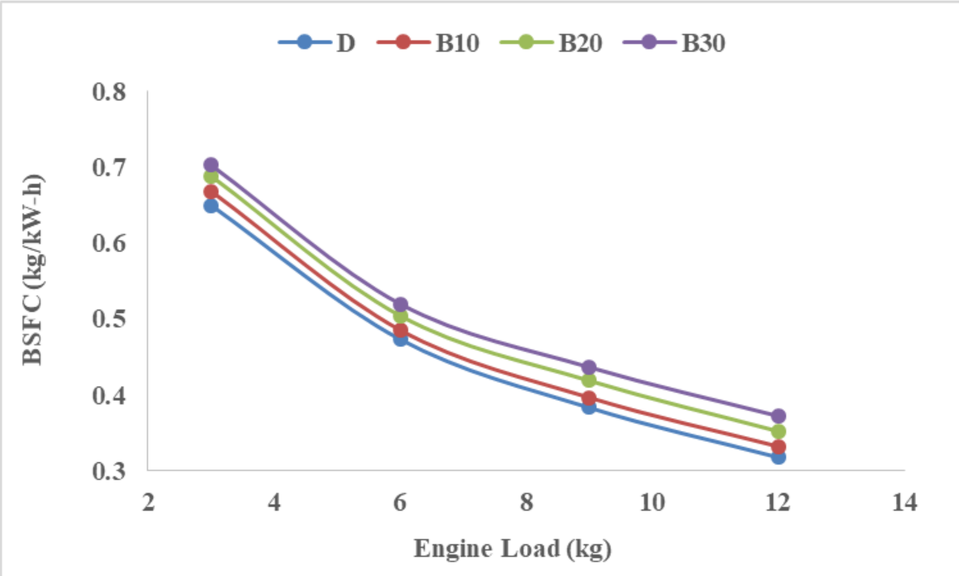


Figure 6: Effect of Engine Load on Brake Specific Fuel Combustion

The highest average BSFC of the engine (0.37 kg/kW-hr) was recorded with B30 blend at 3 kg engine load. While, engine shows lower BSFC (0.32 kg/kW-hr) with diesel at full engine load. At 100% loading condition, the BSFC of the engine is 4.55%, 10.84% and 17.13% lower than biodiesel blends (B10, B20 and B30 respectively).

Effect of Injection Pressure on BSFC:

The effect of increasing fuel injection pressure on BSFC of the engine for various test fuels is exhibited in the figure 7. Figure clears that, increasing the injection pressure from 400 bar to 600 bar decreases BSFC of the engine. This is due to the fact that, with increased injection pressure the fuel is atomized in the very fine fuel droplets. This increases surface to volume ratio of the fuel droplet and increases contact area between fuel droplet and the compressed hot air. Due to this better vaporization and complete combustion of the fuel takes place. Additionally, at any constant injection pressure, the BSFC of the engine increases with increased proportion of the biodiesel. At a constant injection pressure, the atomization and vaporization of the fuel is affected by the properties of the fuel viz. density and viscosity. Increased kinematic viscosity of the fuel increases fuel droplet size, reduces quality of mixture and negatively affects quality of atomization and mixing of fuel [Mofijur2012]. This results in poor combustion of the fuel in the combustion chambers and leads to increases BSFC of the engine.

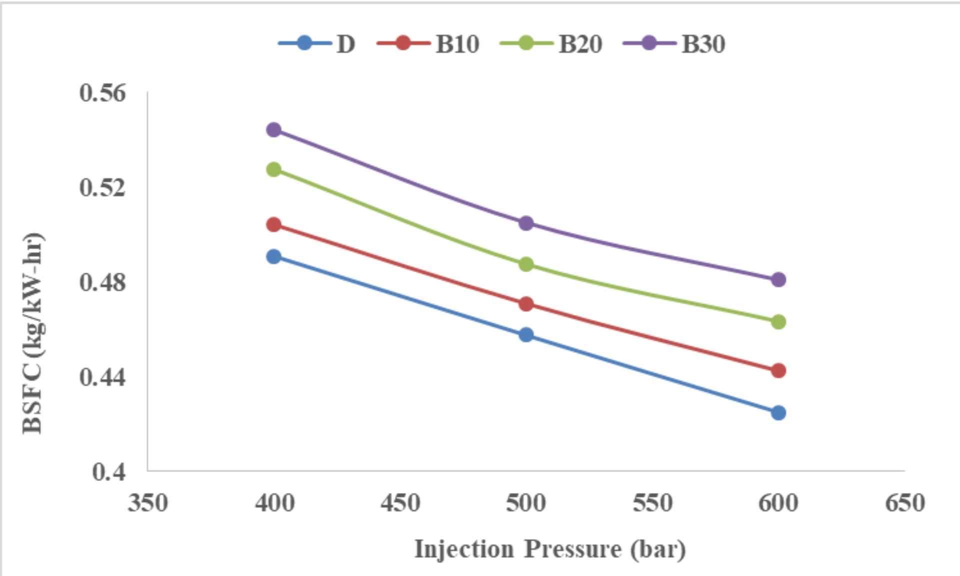


Figure 7: Effect of Injection Pressure on Brake Specific Fuel Consumption

The average BSFC for diesel, B10, B20 and B30 was in the range of 0.49 to 0.55 kg/kWh at 400 bar InP, 0.46 to 0.51 kg/kWh at 500 bar InP and 0.43 to 0.48 kg/kWh at 600 bar InP. In each case of InP, the BSFC of the diesel was lower than that of all biodiesel blends. The BSFC of the diesel at 600 bar InP was recorded as 0.425 kg/kWh which is 13.18% less than B30 blend (0.48 kg/kWh).

Effect of Compression Ratio on BSFC:

The variation of average BSFC of the engine with the compression ratio for diesel as well B10, B20 and B30 biodiesel blend is shown in figure 8. From results it is revealed that, BSFC of the engine decreases with increase in the compression ratio for all test fuels. Higher compression ratio results into higher cylinder pressure and temperature which increases quality of combustion and converts maximum chemical energy of fuel into useful work. The poor combustion characteristics and low calorific value of the biodiesel increases BSFC of all biodiesel blends than diesel. It shown increased BSFC trend with increase in biodiesel proportion in the blend.

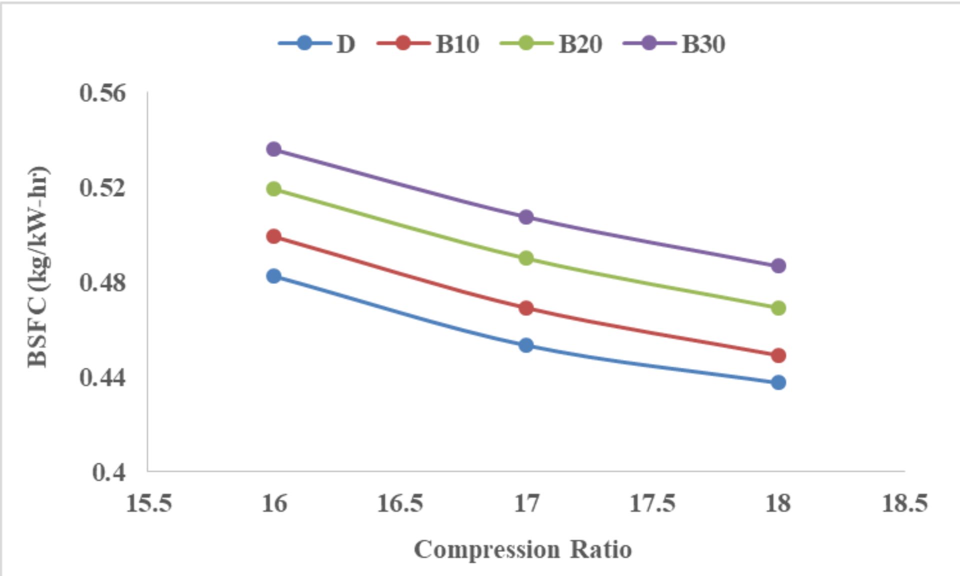


Figure 8: Effect of Compression Ratio on Brake Specific Fuel Consumption

With increase in the compression ratio from 16 to 18, the average BSFC reduces from 0.54 kg/kWh to 0.49 kg/kWh for B30 blend, 0.52 kg/kWh to 0.47 kg/kWh for B20 blend, 0.50 to 0.45 kg/kWh for B10 blend and 0.48 to 0.44 for diesel fuel. At each compression ratio, the performance of the engine with diesel is superior in terms of BSFC than with biodiesel blends.

Mechanical Efficiency:

Due to the mechanical friction between moving parts of the engine, it is not possible to convert all the indicated power into brake power. The mechanical efficiency of an engine measures conversion efficiency of indicated power into brake power. The mechanical friction and hence friction power increases with increase in the engine speed. As all experimental tests are conducted at constant engine speed (1500 rpm), the friction power of the engine for all tests is approximately same. No solid conclusion can be drawn on the effect of varying injection pressure and compression ratio on the mechanical efficiency of the engine. However, for the work under study, the effect of engine load on mechanical efficiency of the engine is investigated. Figure 9 shows the variation of mechanical efficiency with the engine load for injection pressure of 600 bar and compression ratio of 18 as an illustration.

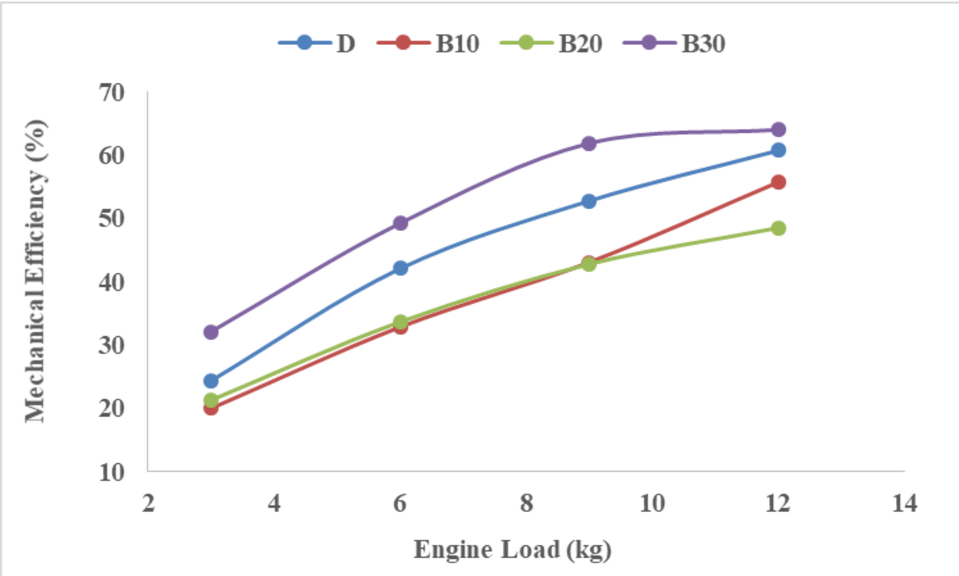


Figure 9: Variation of Mechanical Efficiency with Engine Load

It is clear from the figure that, for all test fuels, the mechanical efficiency of the engine increases with increase in engine load. Due to the constant engine speed, the friction power of the engine at all engine loads varies in the range of 1.6 to 1.9 kW. However, the indicated power of the engine increases with the increase in the engine load. At low engine load, on account of low indicated power, a major share of the indicated power is compensated to overcome friction which results in lower brake power of the engine. As engine load increases, the percentage of the indicated power lost to overcome friction reduces and results in higher mechanical efficiency with rise in engine load. Furthermore, the B30 blend shows higher mechanical efficiency at each loading condition than diesel. Higher viscosity of the biodiesel provides better lubrication properties and aids to increase mechanical efficiency. The mechanical efficiency of the engine varies from 24.38% to 60.74% with diesel and 32.13% to 64.03% for B30 blend.

Conclusion:

Performance characteristics of the single cylinder diesel engine was evaluated using turmeric leaf oil based biodiesel (B10, B20 and B30) at varying operating conditions of engine load, injection pressure and compression ratio. The performance of the engine employing biodiesel blend was compared to that of using pure diesel fuel. The conclusion drawn from the experimental studies are summarized in the subsequent text.

With addition of the biodiesel to the diesel, the density and viscosity of the biodiesel blend increases due to the presence of free fatty acids in the turmeric leaf oil. On the other hand, the caloric value of the diesel decreases with addition of biodiesel due to higher oxygen content of the biodiesel. The rise in engine load tends to increase BTE and decrease BSFC for diesel and all biodiesel blends due to greater conversion rate of chemical energy of the fuel into useful brake power. For all fuels under investigation, increasing fuel injection pressure aids in improving BTE of the engine and reduces BSFC due to better atomization and combustion of the fuel. Increasing the compression ratio results in the improvement in the BTE and minimize BSFC of the engine on account higher cylinder pressure and temperature at higher compression ratio. Higher density and viscosity and lowered calorific value of the biodiesel leads to poor combustion performance and brings down BTE and increases BSFC of the engine with growing percentage of biodiesel in the blend. The enhanced lubricating properties of the B30 blend due to higher viscosity helps to increase the mechanical efficiency of the engine than that of diesel at all engine loads.

Author Contributions:

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript. All authors contributed equally.

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Conflict of interest:

The authors would like to declare there are no conflict of interests.

References:

Ananthakumar, S., S. Jayabal, and P. Thirumal. "Investigation on performance, emission and combustion characteristics of variable compression engine fuelled with diesel, waste plastics oil blends." Journal of the Brazilian Society of Mechanical Sciences and Engineering 39 (2017): 19-28.

Ansari, Naushad Ahamad, Abhishek Sharma, and Yashvir Singh. "Performance and emission analysis of a diesel engine implementing polanga biodiesel and optimization using Taguchi method." *Process Safety and Environmental Protection* 120 (2018): 146-154.

Ariani, F., T. B. Sitorus, and E. Ginting. "The performance and emissions of diesel engines with biodiesel of sunan pecan seed and diesel oil blends." In *IOP Conference Series: Materials Science and Engineering*, vol. 277, no. 1, p. 012045. IOP Publishing, 2017.

Awogbemi, Omojola, Daramy Vandi Von Kallon, Emmanuel Idoko Onuh, and Victor Sunday Aigbodion. "An overview of the classification, production and utilization of biofuels for internal combustion engine applications." *Energies* 14, no. 18 (2021): 5687.

Ayhan, Vezir, Çiçek Çangal, İdris Cesur, Aslan Çoban, Gökhen Ergen, Yusuf Çay, Ahmet Kolip, and İbrahim Özsert. "Optimization of the factors affecting performance and emissions in a diesel engine using biodiesel and EGR with Taguchi method." *Fuel* 261 (2020): 116371.

Cheikh, Kezrane, Awad Sary, Loubar Khaled, Liazid Abdelkrim, and Tazerout Mohand. "Experimental assessment of performance and emissions maps for biodiesel fueled compression ignition engine." *Applied energy* 161 (2016): 320-329.

Dharsini, P., N. Ahalya, S. Kaliappan, S. Sekar, Pravin P. Patil, Varasala Pragna, Gurusamy Pathinettampadian, J. Isaac JoshuaRamesh Lalvani, and Kibrom Menasbo. "Performance and environmental effects of CeO2/ZrO2 nanocomposite in triple blend methyl ester of pumpkin and neem seed oil dosed with diesel on IC engine." *Journal of Nanomaterials* 2022 (2022).

Dinesh, K., A. Tamilvanan, S. Vaishnavi, M. Gopinath, and KS Raj Mohan. "Biodiesel production using Calophyllum inophyllum (Tamanu) seed oil and its compatibility test in a CI engine." *Biofuels* 10, no. 3 (2019): 347-353.

Elkelawy, Medhat, Hagar Alm-Eldin Bastawissi, E. A. El Shenawy, Mohammed Taha, Hitesh Panchal, and Kishor Kumar Sadasivuni. "Study of performance, combustion, and emissions parameters of DI-diesel engine fueled with algae biodiesel/diesel/n-pentane blends." *Energy Conversion and Management: X* 10 (2021): 100058.

Ellappan, Sivakumar, and Silambarasan Rajendran. "A comparative review of performance and emission characteristics of diesel engine using eucalyptus-biodiesel blend." *Fuel* 284 (2021): 118925.

Ghanbari, Mani, Lotfali Mozafari-Vanani, Masoud Dehghani-Soufi, and Ahmad Jahanbakhshi. "Effect of alumina nanoparticles as additive with diesel–biodiesel blends on performance and emission characteristic of a six-cylinder diesel engine using response surface methodology (RSM)." *Energy Conversion and Management: X* 11 (2021): 100091.

http://www.indianspices.com/sites/default/files/majorspicestatewise2021.pdf (accessed on March 27, 2023)

https://agritech.tnau.ac.in/banking/pdf/Tumeric.pdf (accessed on March 27, 2023)

Karthikeyan, S., A. Prathima, M. Periyasamy, and G. Mahendran. "Performance analysis of Al2O3 and C18H34O2 with Kappaphycus Alvarezil-Brown algae biodiesel in CI engine." *Materials Today: Proceedings* 33 (2020): 4180-4184.

Miriam, LR Monisha, Ajith J. Kings, R. Edwin Raj, and M. Adhi Viswanathan. "Algal oil extraction-cum-biodiesel conversion in a novel batch reactor and its compatibility analysis in IC engine at various CRs." *Fuel* 293 (2021): 120449.

Mofijur, M., H. H. Masjuki, M. A. Kalam, M. A. Hazrat, A. M. Liaquat, M. Shahabuddin, and M. Varman. "Prospects of biodiesel from Jatropha in Malaysia." Renewable and sustainable energy reviews 16, no. 7 (2012): 5007-5020.

Mourad, M., Khaled RM Mahmoud, and El-Sadek H. NourEldeen. "Improving diesel engine performance and emissions characteristics fuelled with biodiesel." *Fuel* 302 (2021): 121097.

Murugapoopathi, S., and D. Vasudevan. "Experimental and numerical findings on VCR engine performance analysis on high FFA RSO biodiesel as fuel using RSM approach." *Heat and Mass Transfer* 57, no. 3 (2021): 495-513.

Sanli, Bengi Gozmen, Mustafa Özcanli, and Hasan Serin. "Assessment of thermodynamic performance of an IC engine using microalgae biodiesel at various ambient temperatures." *Fuel* 277 (2020): 118108.

Sayyed, Siraj, Randip Kumar Das, and Kishor Kulkarni. "Performance assessment of multiple biodiesel blended diesel engine and NOx modeling using ANN." *Case Studies in Thermal Engineering* 28 (2021): 101509.

Simsek, Suleyman. "Effects of biodiesel obtained from Canola, sefflower oils and waste oils on the engine performance and exhaust emissions." *Fuel* 265 (2020): 117026.

Spices Board of India, Ministry of Commerce and Industry, Government of India, "Major Spice/state wise area and production of spices", (2021)

Tamilnadu Agricultural University, TNAU Agritech Portal, "Turmeric"