Production Of Bioethanol From Different Leaves Waste And Performance And Emission Characteristics Of Single Cylinder CI Engine

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Abstract

**Background:** The need of bioethanol is being increased nowadays; hence the production of bioethanol must be increased using cheaper and eco-friendly raw materials. Based on these criteria, different leaves wastes are considered as cheaper and eco-friendly. In the present study selected tree leaves wastes such as Rain tree, Jackfruit tree, Mango tree and Singapore cherry tree leaves waste were used as raw materials to produce bioethanol by using *Saccharomyces cerevisiae* (yeast). The operating conditions are pH 6.5, temperature 27±2°C, speed 80rpm, fermentation period 10 days. Also an attempt has been made to find out the suitability of extracted bioethanol as a fuel in CI engine.

**Results:** Experimental work on performance and emission characteristics of ethanol blended diesel fuel was conducted on single cylinder four stroke CI engines at operating pressure 210 bar. The results obtained from this work shows that the higher rate of ethanol can be produced through fermentation of wet Jackfruit tree leaves, which gives good percentage of ethanol as compared to other tree leaves wastes.

**Conclusions:** The conversion of waste into fuel, which forms an attractive solution towards both waste management and Biofuels generation. This study concludes that the Jackfruit tree leaves contain rich fermentable sugar can be converted into useful products like bioethanol that can serve as an alternative energy source.

1. **Background**

The rapid depletions of fossil fuel create negative impact on our environment as greenhouse gas emissions are harmful. The need of fuel is increased because of increase in the vehicles and industries. By using biofuels greenhouse gas emissions are reduced. The production of bio-fuels from plant waste gives an attractive solution towards the waste management and energy generation. The bioethanol produced from feed stocks such as fruits rind part, barley, wheat, etc. In this present study the feed stocks selected are plant wastes such as Rain tree leaves, Jackfruit leaves as possible resources by conversion of plant wastes to fuel [1].

The use of starch and sugar from cassava, corn, and sugar cane are basically human food which leads to the food crisis problem. Agro-industrial bio-fuel comprised on lignocellulose biomass is an inexpensive, renewable, abundant and obtained from the non-food resource [2].

The production of ethanol from leaves involves two stages 1) Hydrolysis of biomass 2) Ethanol fermentation. Hydrolysis of Biomass can be done by using acid or enzyme catalyst. Using acid for hydrolysis produces hazardous environmental acid wastes and also causes difficulties in recovery of sugars. Enzymatic Hydrolysis is environmental friendly and efficient way to convert lignocellulose to bioethanol. The fermentation process is achieved from *Saccharomyces cerevisiae*. *Saccharomyces cerevisiae* is widely known organism that can utilize glucose and xylose for ethanol fermentation [3]. Because of more latent heat of vaporization and oxygen content, bioethanol produced from the
fermentation process are having high octane number and it is less polluting compared to Diesel. Because of their longevity, regeneration after cut-off the leaves are considered as one of the most suitable energy crops.

*Samanea saman* (Rain Tree) is a species of flowering tree in the *Albizia* family. The common name for Raintree includes Saman, monkey pod, giant thibet, ingasaman, cow tamarind, East Indian walnut, soar and suar. *Artocarpus heterophyllus* (Jackfruit) trees belongs to the *Moraceae* family. The jackfruit trees grow in India, Bangladesh and other parts of Southeast Asia. Jackfruit tree leaves are rich in starch and protein. *Muntingia calabura* (Singapore cherry) trees belong to a *Muntingiaceae* family [4]. The common name includes Jamaican cherry, panama berry, Singapore cherry. These thrive in poor soil, able to tolerate acid and alkaline condition and drought. *Mangifera indica* (Mango) trees belong to *Anacardiaceae* family. These trees belong to mangofera genus. These leaves contain 3–15% of lignin and 40% of cellulose.

Hence in our present study leaves waste are considered as raw material for the production bioethanol. This bioethanol is mixed with diesel at different percentages of blends [5].

## 2. Results And Discussion

### 2.1 Essay of ethanol from both Jackfruit and Rain tree leaves

After fermentation ethanol obtained from both Jackfruit and Rain tree leaves was estimated by GC-MS method. Description of the samples and estimated ethanol percentages were given in Table 1 and 2. The two bar graphs shown in Figs. 1 and 2 represents type of samples and ethanol percentage.

| Jackfruit Leaves Sample | Ethanol Assay (%) |
|-------------------------|-------------------|
| 1) Wet Jackfruit         | 4.34              |
| 2) Dry Jackfruit         | 1.60              |
| 3) Dry Jackfruit + NaOH  | 2.27              |
| 4) Dry Jackfruit + NaOH + HS | 2.51          |
| 5) Dry Jackfruit + Na₂SO₄ | 3.15              |
| 6) Dry Jackfruit + Na₂SO₄ + HS | 3.33          |
| 7) Dry Jackfruit + NaOH + Na₂SO₄ | 3.51        |
| 8) Dry Jackfruit + NaOH + Na₂SO₄ + HS | 4.23       |
| 9) Dry Jackfruit + HS    | 1.93              |
Table 2
Ethanol percentage by GC-MS after fermentation in Rain tree leaves sample

| Rain tree Leaves Sample                      | Ethanol Assay (%) |
|---------------------------------------------|-------------------|
| 1) Wet Rain tree                            | 3.52              |
| 2) Dry Rain tree                            | 0.97              |
| 3) Dry Rain tree + NaOH                     | 1.04              |
| 4) Dry Rain tree + NaOH + HS                | 1.17              |
| 5) Dry Rain tree + Na₂SO₄                    | 1.52              |
| 6) Dry Rain tree + Na₂SO₄ + HS               | 2.02              |
| 7) Dry Rain tree + NaOH + Na₂SO₄             | 2.30              |
| 8) Dry Rain tree + NaOH + Na₂SO₄ + HS        | 2.46              |
| 9) Dry Rain tree + HS                       | 1.02              |

From GC-MS results we have got more percentage of ethanol in wet jackfruit after fermentation. The percentage of ethanol in Wet jackfruit sample was found to be 4.34% and in dry Jackfruit leaves percentage of ethanol was found to be 4.23%. We have selected wet Jackfruit leaves for the scale up production of bioethanol.

The results obtained by performing experiments under pure Diesel mode and Ethanol blended diesel fuel mode and results are shown in Figs. 3–10.

Table 3. Properties of fuels

| Properties               | Percentage of Ethanol blends with Diesel |
|--------------------------|------------------------------------------|
|                          | 0%  5%  10%  15%  100%                  |
| Flash point °C            | 53  51  43  37  16                      |
| Fire Point °C             | 59  54  48  42  18                      |
| Density Kg/m³             | 840 839.4 839.1 838.9 836               |
| Kinematic Viscosity mm²/sec| 3.15 2.87 2.71 2.57 1.3                  |
| Calorific value MJ/kg     | 43  42.7  42.48  42.21  19.2           |
2.2 Evaluation of properties for Diesel and different blends

Open cup apparatus is used to determine Flash point and Fire point. Redwood viscometer is used to determine density and kinematic viscosity. Bomb calorimeter is used to determine Calorific value [6, 7, 8].

2.3 Brake specific fuel consumption (BSFC)

The Fig. 3 illustrates the variation of BSFC with BP for Diesel, 5% blend, 10% blend, 15% blends. The BSFC decreases with increase in BP for Diesel and for different blends. As compared to Diesel the BSFC are decreased for Ethanol fuel blends due to decrease in Calorific value. At 0.58 kW BP the difference between Diesel point and 15% ethanol blend point the BSFC is decreased by 8% compared to Diesel. At 4.11 kW BP we observed that there is 13% decrease in BSFC for 15% ethanol blend point than Diesel. So as the percentage of ethanol blend increases the BSFC value decreases respectively. Thus 15% ethanol blend has lower BSFC compared to other blends and Diesel for various loads [9].

2.4 Brake thermal efficiency (BTE)

The Fig. 4 illustrates the variation of BTE with BP for Diesel and different ethanol fuels blend. The BTE increases with increase in BP for both Diesel and ethanol fuel blends [10]. Due to lower calorific value and higher latent heat of vaporization as the percentage of ethanol fuel blends increases in Diesel the BTE increases as compared to diesel fuels. At 0.58 kW BP we observed that there is 23% increase in BTE for 15% ethanol blend compared to Diesel. At 4.11 kW BP we observed that there is 14% increment in BTE for 15% ethanol fuel blend compared to Diesel. Thus for 15% ethanol blend has higher BTE compared to other ethanol blends and Diesel for different loads.

2.5 Exhaust gas temperature (EGT)

The Fig. 5 shows the variation of EGT with BP for Diesel and various percentage ethanol fuel blends. Exhaust gas temperature for ethanol fuel blends decreases as compared to Diesel because as the percentage of ethanol blend increases which increases the oxygen in the fuel blends which gives cooling effect to the engine hence reduces the exhaust gas temperature. Lower calorific value of ethanol fuel blends also decreases the exhaust gas temperature. For 0.58 kW BP there is 11% decrease in exhaust gas temperature for 15% ethanol fuel blend as compared to Diesel. At 4.11 kW 9% decrease in exhaust gas temperature for 15% ethanol fuel blends compared to Diesel. Thus for 15% ethanol fuel blend has lower exhaust gas temperature compared to other blends and Diesel for various loads.

2.6 Peak pressure rise

The Fig. 6 illustrates the variation of Peak pressure rise with BP for Diesel and various percentages of ethanol blends. Ethanol has more content of oxygen and rapid combustion will occur hence sudden peak pressure rise was achieved. As the BP increases the peak pressure rise is higher in ethanol fuel blends and lower pressure rise in diesel for various loads. Thus 15% ethanol fuel blends is having higher peak pressure rise as compared to other fuel blend and diesel for various loads.

2.7 Carbon monoxide (CO) emissions
The Fig. 7 illustrates the variations of CO emissions with BP for Diesel and various ethanol blends. It is indicated that CO emissions are decreased with increase in percentage of ethanol blend compared to Diesel. Ethanol is oxygenated fuel so ethanol blends have more content of oxygen compared to diesel and gives complete combustion and also reduces the emissions of CO. At 0.58 kW BP about 50% of CO emissions are reduced for 15% ethanol blend compared to diesel. At 4.11 kW BP about 27% of CO emissions are reduced for 15% ethanol blend compared to diesel. Thus graph shows that 15% of ethanol blend has lower CO emissions compared to other ethanol fuel blends and diesel at various loads.

2.8 Carbon Dioxide (CO$_2$) emissions

The Fig. 8 illustrates the variation of Carbon Dioxide (CO$_2$) emissions with Brake power (BP) for various ethanol fuel blends and diesel. Due to more oxygen content in ethanol fuel blends complete combustion will occur. This result in decrease in CO$_2$ emissions for ethanol blend compared to diesel. So as BP increase CO$_2$ emissions will be reduced. At 0.58 kW BP about 32% of CO$_2$ emissions will be reduced for 15% ethanol fuel blend compared to diesel. At 4.11 kW BP about 17% of CO$_2$ emissions will be reduced for 15% ethanol fuel blends compared to diesel. Thus from above graph it is concluded that for 15% ethanol blend has lower CO$_2$ emissions compared to other ethanol fuel blends and diesel at various loads.

2.9 Hydrocarbon (HC) emissions

The Fig. 9 illustrates the variation of HC emissions with BP for various Ethanol blends and diesel. Ethanol blends having high latent heat of vaporization and low Cetane number, which reduces the exhaust gas temperature and promote the rapid combustion hence with increase in percentage of ethanol blends increases the Hydrocarbon emission compared to diesel. As Brake power increases hydrocarbon emissions also increases with increase in percentage of ethanol blends. At 0.58 kW BP about 38% of hydrocarbon emissions will be increased for 15% ethanol blends compared to diesel similarly at 4.11 kW BP about 19% of hydrocarbon emissions will be increased for 15% ethanol blend than diesel. Thus the above graph shows that there will be increase in HC emissions for ethanol blends compared to diesel for various loads.

2.10 NO$_X$ Emissions

The Fig. 10 illustrates the variation of NO$_X$ emissions with BP for various ethanol blends and diesel. The NOx formation is highly influenced by combustion temperature. From the graphs, it was observed that the NOx emission increases with the increase in load for diesel and various blended fuels. Moreover at all load ranges, the NOx emission is less for all blended fuels when compared with that of diesel. The high latent heat of vaporization and lower calorific value of ethanol reduces the cylinder temperature which in turn reduces the NOx emissions. At 0.58 kW BP about 24% of NO$_X$ emissions were decreased for 15%ethanol blend compared to diesel. Similarly at 4.11 kW BP about 13% of NO$_X$ emissions were decreased for 15% ethanol blend than diesel [11].
3. Conclusion

From results obtained following conclusions are made

1. In this present study, selected leaves wastes such as Rain tree leaves, Jackfruit tree leaves, Singapore cherry tree leaves, Mango tree leaves were considered as raw materials for the production of Bioethanol and the conversion of waste into fuel, which forms an attractive solution towards both waste management and Biofuels generation.

2. Due to more starch content in Jackfruit tree leaves and Rain tree leaves we have selected these leaves for the production of bioethanol. The percentage of ethanol from Gas Chromatography-Mass Spectrometry was found to be 4.34% in Wet Jackfruit tree leaves and 4.23% in Dry Jackfruit tree leaves. In Wet Rain tree leaves the percentage of ethanol was found to be 3.52% and in Dry Raintree leaves it was found to be 2.46%.

3. The extracted Bioethanol from wet Jackfruit tree leaves wastes and analysis of fuel properties, the performance and emission characteristics of single cylinder CI engine were carried out.

4. The Brake specific fuel consumption (BSFC) of ethanol blended diesel was decreased because ethanol blended diesel have lower calorific value and lower Cetane number compared to diesel. At 0.58kW BP about 8% BSFC was decreased for 15% ethanol blend compared to diesel. At 4.11kW BP about 13% decrease in BSFC for 15% ethanol blend compared to diesel.

5. The Brake thermal efficiency (BTE) of ethanol blended fuel is increased with increase in Brake power (BP) as compared to diesel. This is because the ethanol blend diesel has more oxygen content and high latent heat of vaporization as compared to diesel which promotes the combustion. At 0.58kW BP about 23% BTE was increased and at 4.11kW BP about 14% BTE was increased compared to diesel.

6. The ethanol blend diesel has more oxygenated fuel compared to diesel and results in complete combustion. Hence CO emissions will be reduced for ethanol blend diesel compared to diesel. At 0.58kW BP about 50% of CO emissions will be reduced and at 4.11kW BP about 27% of CO emissions are reduced compared to diesel [12].

7. The ethanol blend fuel decreases the CO$_2$ emissions compared to diesel because of complete combustion. At 0.58kW BP about 32% of CO$_2$ emissions are reduced and at 4.11kW BP about 17% of CO$_2$ emissions are reduced compared to diesel.

8. Due to rapid combustion the hydrocarbon emissions will be more for ethanol blend diesel compared to diesel. At 0.58kW BP about 38% of HC emissions will be increased and at 4.11kW BP about 19% of HC emissions are increased compared to diesel for Jackfruit leaves ethanol [13].

9. NOx emission increases with the increase in load for diesel and various blended fuels. Moreover at all load ranges, the NOx emission is less for all blended fuels when compared with that of diesel. The high latent heat of vaporization and lower calorific value of ethanol reduces the cylinder temperature which in turn reduces the NOx emissions. At 0.58kW BP about 24% of NO$_x$ emissions were decreased.
for 15% ethanol blend compared to diesel. Similarly at 4.11kW BP about 13% of NO\textsubscript{x} emissions were decreased for 15% ethanol blend than diesel.

### 4. Materials And Methods

#### 4.1 Microorganism and Culture media

The media was prepared with 22.75 g of Sabouraud Dextrose Agar (SDA) in 350 ml of distilled water in a 1000 ml conical flask and mixed well thoroughly, which was plugged with cotton plug and sterilized or autoclaved for 30 min at 15psi and 121 °C. Then the media is allowed to cool to the room temperature and the medium is equally distributed petri dishes in laminar flow chamber. The SDB media was prepared by adding 65 g of Sabouraud Dextrose Broth (SDB) to 1000 ml of distilled water and mixed well thoroughly which was plugged with cotton plug and autoclaved (sterilized) for 30 minutes at 15psi and 121 °C. Sabouraud Dextrose Broth (SDB) with an organism is allowed to grow for 24 hours.

#### 4.2 Collection of raw material

Lignocellulosic dry and wet leaves such as Rain tree leaves, Jackfruit leaves, Singapore cherry leaves, Mango tree leaves were taken from agricultural rural areas \[14\]. All the leaves samples were dried and grounded into powder.

#### 4.3 Iodine test to determine starch content in leaves

The iodine test is conducted to determine the starch content in the different plant leaves. The plant leaves have green parts (where the cells contains chlorophyll) and white parts (where there is no chlorophyll). Only the parts that were green becomes blue-black with iodine solution. From this test we observed that there is more starch content in Jackfruit and Rain tree leaves compared to Mango tree and Singapore cherry leaves \[15\]. We selected Rain tree and Jackfruit tree leaves for the production of bioethanol.

#### 4.4 Extraction of juice from different plant wastes

About 50 g of wet leaves of Rain tree and jackfruit trees are weighed separately and which was rinsed with water and then washed and added 250 ml of distilled water. The wet leaves of rain tree and jackfruit trees were separately crushed in a mixer and stored in a conical flask. Similarly the dry leaves of the jackfruit trees and rain trees are collected and cleaned with distilled water and dried in sunlight for reduction of moisture content in the leaves \[16\]. About 500 g of dry leaves of both trees were weighed separately and 25 g of each plant wastes are taken in 10 different 250 ml conical flask and 100 ml of water is added.

#### 4.5 Fermentation process

The 250 ml juice of wet leaves of both rain trees and jackfruit trees are taken in 500 ml conical flask and which were plugged with cotton plug. The content was autoclaved for 30 minutes at 15psi and 121 °C.
The 25 g of each dry rain tree and jackfruit tree leaves are weighed separately and were taken separately in 9 different 250 ml conical flasks and 100 ml of distilled water is added for each conical flask [17].

750 mg of sodium hydroxide is added for 2 conical flasks of each plant leaves Heat Shock treatment is given for 1 conical flask of each samples.

750 mg of sodium sulphate is added for another 2 conical flasks of each plant leaves and Heat Shock treatment is given for 1 conical flask of each samples.

750 mg of each sodium hydroxide and sodium sulphate is added for another 2 conical flasks of each plant leaves and Heat Shock treatment is given for 1 conical flask of each samples.

For remaining 3 conical flasks of each plant leaves no chemicals were added. Only control is maintained. Heat Shock (HS) is given for 1 conical flask at 10 power 5 minutes of each leaves and remaining 2 conical flasks were used for biochemical tests and were plugged with cotton plug and were autoclaved for 30 minutes at 15psi, 121 °C. Pre-treatment of lingo cellulose biomass by microwave irradiation is based on non-thermal and thermal effects of microwaves. Heating is very essential parameter in pre-treatment technology. Higher temperature accelerates the reaction rate and minimizes the chemicals requirement during pre-treatment [18].

The process was continued to find the pH values of specimens by using pH paper method. These contents were allowed to cool and 10% of Saccharomyces cerevisiae culture was inoculated in 9 different 250 ml conical flask of each plant leaves in laminar air flow chamber. The media was incubated for 10days at 27 ± 2 °C temperature, 80 rpm in rotary shaker incubator [19]. After 10days of incubation the media was filtered and centrifuged at 13000 rpm for 10minutes to remove cell and suspended particles. The supernatant was collected and Gas chromatography and mass spectrometry (GC-MS) test was conducted for the estimation of ethanol content [20].

4.6 Determination of Carbohydrate by Anthrone Reagent method

The major constraint beyond the carbohydrate estimation is that carbohydrates are dehydrated with concentrated H$_2$SO$_4$ to form furfural. This furfural condenses with Anthrone reagent to form green colour which is measured by calorimeter at 670 nm. Anthrone reagent was prepared by dissolving 100 mg of Anthrone reagent in 50 ml of concentrated Sulphuric acid [21]. Standard Glucose was prepared by Adding 100 mg of Glucose or Maltose to 50 ml of distilled water.

4.7 Engine setup

The experiments were conducted on 4 Stroke, Single Cylinder Diesel engine with electrical loading is as shown in Fig. 11.

1. 1. Diesel engine 2. Generator 3. Electrical load
2. 4. Fuel tank 5. Pressure pickup 6. Shaft encoder 7. Computer 8. Exhaust gas analyzer
Table 4
Engine specifications

| Company   | Kirloskar                      |
|-----------|--------------------------------|
| Engine type | Four Stroke Single Cylinder    |
| Power      | 5.2 kW                         |
| Stroke     | 110 mm                         |
| Speed      | 1500 rpm                       |
| Compression Ratio | 17.5:1                      |
| Cooling    | Water Cooled                   |
| Fuel injection | Mechanical injection with injection timing 23°bTDC |
| Injection pressure | 210 bar                  |

4.7.1 Exhaust gas analyser

AVL DIGAS 440 gas analyser as shown in Fig. 12 is a device used to measure the emissions.

Table 5
Data showing the measurement resolution of emissions

| Emissions | Resolutions |
|-----------|-------------|
| HC        | 1 ppm       |
| CO        | 0.01%       |
| CO₂       | 0.01%       |
| O₂        | 0.01%       |
| NO₅       | 1 ppm       |

Abbreviations

BSFC: Brake specific fuel consumption; BTE: Brake thermal efficiency; EGT: Exhaust gas temperature; HC: Hydrocarbon; BP: Brake power; SDA: Sabouraud Dextrose Agar; SDB: Sabouraud Dextrose Broth; HS: Heat Shock; GC-MS: Gas chromatography and mass spectrometry.

Declarations
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Authors' contributions

Dr. Ir. Sreenivas Reddy Bathula conducted fermentation related work including manuscript preparation; Vikas S Ballary mechanical lab work; Dr. Kumarappa engine data analysis; Guruchethan A.M. produced figures, graphs and conducted CI engine studies; Harika Mali contributed to the discussion and results analysis. All authors contributed to editing the manuscript. All authors read and approved the final manuscript.

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Availability of data and material

The authors confirm that the data supporting the findings of this study are available within the reference articles and in its supplementary materials.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Information

Supplementary information accompanies this paper

Additional file 1: Comparison of Ethanol percentage in various Jackfruit sample

Additional file 2: Comparison of ethanol percentage in Rain tree leaves sample

Additional file 3: Variation of BSFC with BP for Diesel and various blend of ethanol

Additional file 4: Variation of BTE with BP for Diesel and various blend of ethanol

Additional file 5: Variation of EGT with BP for Diesel and various blend of ethanol

Additional file 6: Variation of Peak pressure rise with BP for Diesel and various blend of ethanol

Additional file 7: Variation of CO emissions with BP for Diesel and various blend of ethanol
Additional file 8: Variation of CO2 emissions with BP for Diesel and various blend of ethanol
Additional file 9: Variation of HC emissions with BP for Diesel and various blend of ethanol
Additional file 10: Variation of NOx emissions with BP for Diesel and various blend of ethanol
Additional file 11: Line diagram of single cylinder, four stroke Diesel engine
Additional file 12: Exhaust gas analyser

Figures

![Comparison of Ethanol percentage in various Jackfruit sample](image)

Figure 1

Comparison of Ethanol percentage in various Jackfruit sample
Figure 2

Comparison of ethanol percentage in Rain tree leaves sample.
Figure 3

Variation of BSFC with BP for Diesel and various blend of ethanol
Figure 4

Variation of BTE with BP for Diesel and various blend of ethanol
Figure 5

Variation of EGT with BP for Diesel and various blend of ethanol
Figure 6

Variation of Peak pressure rise with BP for Diesel and various blend of ethanol
Figure 7

Variation of CO emissions with BP for Diesel and various blend of ethanol
Figure 8

Variation of CO2 emissions with BP for Diesel and various blend of ethanol
Figure 9

Variation of HC emissions with BP for Diesel and various blend of ethanol
Figure 10

Variation of NOx emissions with BP for Diesel and various blend of ethanol

Supplementary Files

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