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Comparison of yield for the extraction of *Solanum virginianum* bio-oil with different solvents

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Bio-oil is a promising alternative energy source, offering a potential substitute for conventional fuels upon upgrading. This study is focused on extracting *Solanum virginianum* bio-oil using various solvents to compare the yields. Bio-oil derived from different feedstocks, including used cooking oil and non-edible sources, shows a calorific value of approximately 35 MJ/kg and a viscosity of 40 cP at 40°C. The energy density of this material, ranging from 20 to 25 MJ/kg, is comparable to traditional fossil fuels, making it a viable option for power generation. The ease of storage and transportation of this oil enhances its attractiveness to gaseous fuels. The applications of bio-oil include its use in gas turbines, diesel engines, and boilers and as a biofuel for transportation. Soxhlet extraction, known for its efficiency, simplicity, and cost-effectiveness, has been used to extract compounds from *Solanum virginianum* seeds. The proposed method is widely applied across industries, including natural products, environmental analysis, food, pharmaceuticals, and chemical analysis.

Keywords: Bio-oil, Extraction, Fatty acids, *Solanum virginianum* seed, Soxhlet apparatus

Introduction

The energy crisis influenced the rise of biodiesel manufacturing. The resources for petroleum, charcoal, and natural gas are finite and will run out within the next century, so finding alternate sources of energy is crucial[1]. Vegetable oils are a renewable and possibly endless source of energy with an energetic content close to diesel fuel. Because it is generated from renewable resources and has positive environmental effects, biodiesel has grown in popularity as an alternative fuel in recent years. India, a tropical nation, has many plants in its forests that produce many oilseeds. Ramachandran *et al*. discussed a diesel fuel substitute to protect the environment and weather economic downturns[2]. They discussed how bio-oil is made, its content, qualities, and prospective uses for bio-oil in the future. The seeds of the *Solanum virginianum* plant have a high oil content that can be used to make bio-oil. The information on the fatty acid contents of *Solanum virginianum* seeds is already described in the literature[3,4]. Extensive studies are needed to update the status of various seeds used in bio-oil production. This includes research on the latest methods for extracting bio-oil, advancing technologies for converting bio-oil into biodiesel, and assessing the fuel properties of bio-oil, such as its energy content and environmental impact. The technological approaches that can be used to create bio-diesel are also discussed, along with their benefits and drawbacks[5].

Many people believe that bio-oil is a significant future source of renewable energy and bio fuel. The key benefits of using this bio fuel are that it is renewable, produces better-quality exhaust gas emissions, is biodegradable, and does not increase atmospheric CO_2 levels in a way that would cause the greenhouse effect[6,7]. Biodiesel is made from natural organic matter, such as plants and animal oils, and is incredibly renewable. It is produced sustainably and never runs out. When burned, biodiesel is a non-toxic fuel that emits fewer emissions than fossil fuels. This decrease in air pollution reduces the risk of respiratory disorders, facilitating safe and simple transportation and storage[8].

Bio-oils are typically dark brown, freely flowing organic liquids that are chemically complex, highly oxygenated, viscous, and caustic. Organic species groups, including organic acids, esters, alcohols, and fatty acids, are present in the chemical makeup. Bio-diesel's greater lubricating properties compared to fossil fuel enable smoother engine operation[9]. It essentially functions as a solvent and aids in removing sediments from the engine. It prevents the collection of further deposits inside the engine because of its lubricity. The problems associated with coal and oil extraction, drilling, shipping, and processing can all be eliminated by the use of bio-diesel. Also, it lessens the pollution brought on by fossil fuels. Even waste cooking oil can be converted into this fuel[10].

Bio-oil, derived from used cooking oil and non-edible oil, presents a promising alternative energy source. After upgrading, the vehicle can replace conventional fuels due to its comparable energy density and ease of storage[11]. Researchers focused their study on the stability of bio-oil produced from empty fruit bunches. With an energy density of 20-25 MJ/kg, bio-oil serves as a potential feedstock for power generation, making it suitable for gas turbines, diesel engines, boilers, furnaces, and combustors. Furthermore, bio-oil can be upgraded as a transportation biofuel[12,13].

Solanum virginianum seeds are valued for their multifaceted significance. In traditional medicine practices across various cultures, these seeds have been utilized for their perceived medicinal properties, including anti-inflammatory[14], analgesic, and antimicrobial effects. Scientific research has delved into their pharmacological potential, identifying bioactive compounds like alkaloids and flavonoids[15]. These compounds have shown promise in drug development endeavours. Moreover, *Solanum virginianum* seeds boast a rich nutritional profile, containing essential nutrients such as proteins, carbohydrates, fats, vitamins, and minerals[16,17]. Beyond their medicinal and nutritional value, these seeds play a role in ecological systems, contributing to biodiversity, ecosystem health, and soil conservation efforts. Overall, *Solanum virginianum seeds* hold significance across traditional, scientific, nutritional, ecological, and economic domains[18,19].

Experimental Section

Raw seeds

Solanum virginianum seeds were collected. The seeds were stored at room temperature and primarily the seeds were separated from the husk. The separated seeds were shade-dried for up to 15 days at room temperature and then ground using a kitchen grinder to get fine particles[20].

Solvent Extraction

In the extraction process, five different solvents with varying boiling points were chosen for the study and the solvent giving the highest yield percentage was chosen as the best solvent. The solvents used for the investigation include n-hexane, acetone, benzene, dichloromethane, and isopropanol. The solvents were procured from M/s SRL Chemicals India Ltd, Chennai.

In earlier periods pressing by mechanical methods was employed to extract oil from the seeds. But, at present soxhlet apparatus was used for the extraction process. In this present work, the soxhlet apparatus was slightly modified, where the round bottom flask (500 mL) with the extraction solvent was taken and the soxhlet extractor (500 mL capacity) was placed over it. The bulb-condenser was connected to the top end of the soxhlet extractor and it functioned with the help of cooling water. As the solvent was heated, the vapour passed through the distillation column and fall into the chamber containing the seeds. The condenser enabled the solvent vapour to get cooled and dripped back into the chamber[21,22]. Thus, the solvent had intimate contact with the seeds in the form of vapour and the oil was extracted from the seeds. The mass transfer took place when the condensed vapour moved freely through the cylindrical filter cloth containing the crushed seeds[23]. The two main factors that determined the yield percentage of the oil were the contact time between the seed and the solvent and the surface area of the seed bed. Finely pulverized *Solanum virginianum* seeds were used in the process as it was hard to extract oil from the whole seeds or the coarsely crushed seeds[24]. The seeds were loaded inside the filter cloth cut cylindrically and kept inside the thimble instead of placing the seeds into them directly. Once the chamber was filled with the solvent a cyclic siphoning action took place and the chamber was emptied and the solvent went down into the round bottom flask[25]. This cycle was repeated several times until the extraction process was complete. The schematic representation of the soxhlet apparatus shows the setup used for oil extraction (Fig. 1). It was run for about 3- 3.5 h depending on the solvent[26].

Choice of solvents

The extraction process was carried out using different solvents for varying intervals (1.5, 2.5, 3.5, and 4 h) to determine the best solvent that would yield the maximum percentage. The solvents used were hexane and isopropanol. Seed weight of 75 g and approximately 500 mL of solvent are taken in the distillation flask. Oil leaching occurs at the boiling point of the respective solvents, and the process continued until a clear liquid was obtained, indicating complete oil discharge from the seeds. The seeds were removed at the end of each batch run. A simple batch distillation technique was employed to extract the oil-solvent mixture. The oil yield percentage was calculated using the following equation:

$$\text{Oil Yield}(\%) = \frac{\text{Weight of extracted oil}}{\text{Weight of seed}} \text{X}100$$

The extraction process depended solely on the solubility of the oil in the respective extraction solvent, which varies for each solvent chosen. The other parameters, such as condenser range, bed height, and apparatus capacity, remained constant.

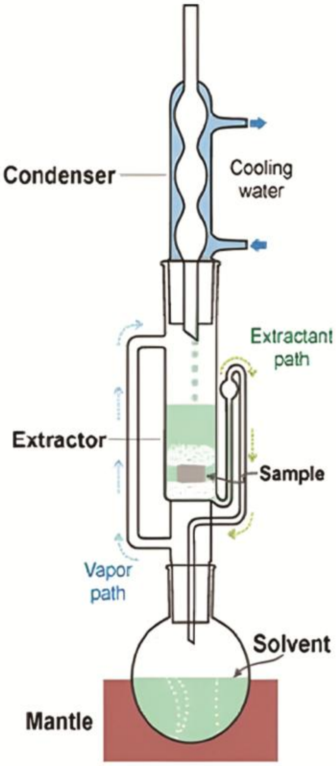

Fig. 1 — Soxhlet apparatus

Results and Discussion

The preparation of bio-oil from *Solanum virginianum* seeds comprises several essential steps. Initially, mature seeds undergo thorough cleaning to eliminate impurities. Once cleaned, the seeds are dried to achieve optimal moisture levels[27]. Subsequently, they are crushed or ground into smaller particles to enhance the extraction surface area. The extraction process typically employs solvent extraction utilizing a soxhlet apparatus, employing solvents like hexane or ethanol[28,29]. Post-extraction, solvent evaporation yields crude bio-oil. This crude bio-oil undergoes purification to eliminate impurities, commonly through filtration or other methods. Following purification, the bio-oil undergoes characterization using analytical techniques like gas chromatography-mass spectrometry to assess its quality and composition[30,31]. Finally, the bio-oil is stored in appropriate containers, shielded from light and heat to preserve its integrity. This process facilitates the conversion of *Solanum virginianum* seeds into bio-oil[32,33], suitable for diverse applications, including biofuel production and pharmaceutical purposes[34].

Effect of using different solvents

The yield of *Solanum virginianum* seeds was highest when using benzene, a non-polar solvent. Fig. 2 delineates the percentage yield of *Solanum virginianum* bio-oil using various solvents used in the extraction process. The results reveal that the yield is high with benzene and acetone, which filtered the highest percentage of oil compared with other solvents such as dichloromethane, isopropanol, and hexane. The yields of bio-oil using different solvents, namely n-hexane, isopropanol, dichloromethane,

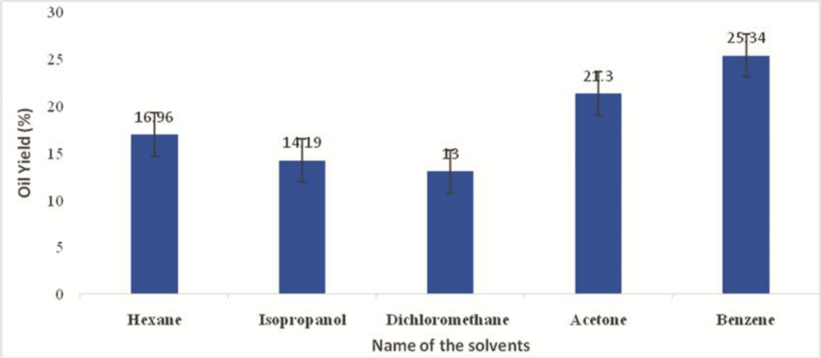

Fig. 2 — Solvent effect on yield of bio-oil

acetone, and benzene, were 12.72, 10.64, 9.40, 15.96, and 19.00 g, respectively.

Effect of extraction time

For each solvent, extraction times were tested over a range of 3 to 5 h. Notably, a significant improvement in yield was observed, with the maximum yield achieved after 3.5 h of extraction. This indicates that a longer extraction time allows for a more thorough extraction of bio-oil from the source material. Conversely, yields were lower for extraction times shorter than 3.5 h, leading to incomplete extraction. This adjustment ensures adequate recovery of bio-oil while optimizing the extraction process, as detailed in Table 1.

Optimization of reaction parameters

The extraction of bio-oil was carried out, and its physicochemical properties were analyzed to determine its suitability as a fuel. The flash point of the bio-oil was found to be 60°C, indicating the temperature at which it can vaporize to form an ignitable mixture in air. The fire point, slightly higher at 63°C, signifies the temperature at which the oil will sustain combustion. The cloud point was measured at -10°C, which is the temperature at which wax crystals begin to form, while the pour point was significantly lower at -34°C, indicating the temperature at which the oil becomes semi-solid and loses its flow characteristics. The specific gravity of the bio-oil was recorded at 0.12%, showing its relative density compared to water. Additionally, the carbon residue was determined to be 1.107%, indicating the amount of carbon left after combustion. These properties collectively suggest that bio-oil has promising potential as an alternative fuel, offering favourable characteristics for various applications, as shown in Table 2.

Quantitative analysis of stability and applications

The study examined the stability and potential applications of bio-oil produced from empty fruit bunch. The energy density of bio-oil, measured at approximately 20–25 MJ/kg, aligns closely with conventional fossil fuels, making it a viable alternative. Additionally, the bio-oil demonstrated a storage stability of up to 12 months under optimal conditions, ensuring its practicality for long-term use.

Table 1 — Effect of extraction time on bio-oil yield

Extraction time (h)	Yield (%)
3	15.2
3.1	16.5
3.2	18
3.3	19.8
3.4	21
3.5	22.5

Table 2 — Basic fuel properties of bio-oil

Basic fuel properties	Values
Flash point (°C)	60
Fire point (°C)	63
Cloud point (°C)	-10
Pour point (°C)	-34
Specific gravity (%)	0.12
Carbon residue	1.107

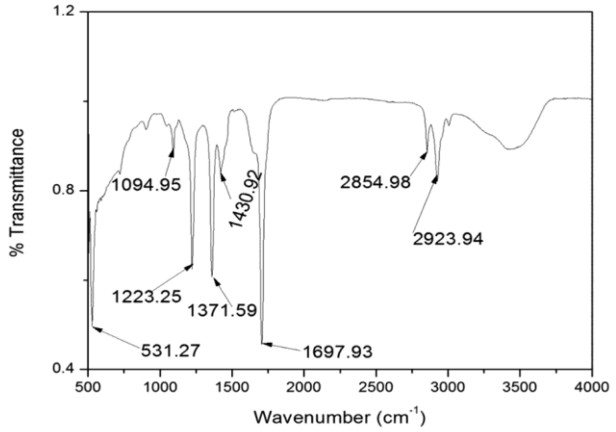

Fig. 3 — FTIR spectrum of bio-oil

Bio-oil's versatility was highlighted by its potential application in various energy systems, including gas turbines, diesel engines, boilers, furnaces, and combustors. Soxhlet extraction, utilized in this study, proved to be an efficient and cost-effective method for extracting compounds from oil seeds. This process is not only simple but also widely applicable in industries such as natural products, environmental analysis, food, pharmaceuticals, and chemical analysis. The findings suggest that bio-oil, with its high energy density and storage stability, can effectively replace petroleum-based fuels in the power generation and transportation sectors, contributing to a more sustainable energy future.

FTIR analysis

FTIR spectrum of the bio-oil is shown in Fig. 3 and its vital peaks are indicated in Table 3. From the spectra C=O stretching frequency of conjugated aldehydes was observed at 1697.93 cm^{-1}. The absorbance at 2923.94 and 2854.98 cm^{-1} indicated C-H stretching of alkanes. The presence of carboxylic acids and phenols is confirmed by the peaks at 1430.92 and 1371.59 cm^{-1} corresponding to O-H bending. FTIR shows the peaks at 1223.25 and 1094.95 cm^{-1}, representing the C-O stretching

Table 3 — Functional groups present in bio-oil

Frequency (cm^{-1})	Functional Group	Mode of Vibration	Class of Compounds
2923.94, 2854.98	C-H	Stretching	Alkane
1697.93	C=O	Stretching	Conjugated aldehyde
1430.92	O-H	Bending	Carboxylic acid
1371.59	O-H	Bending	Phenol
1223.25	C-O	Stretching	Alky aryl ether
1094.95	C-O	Stretching	Secondary alcohol
531.27	C-Br	Stretching	Halo compound

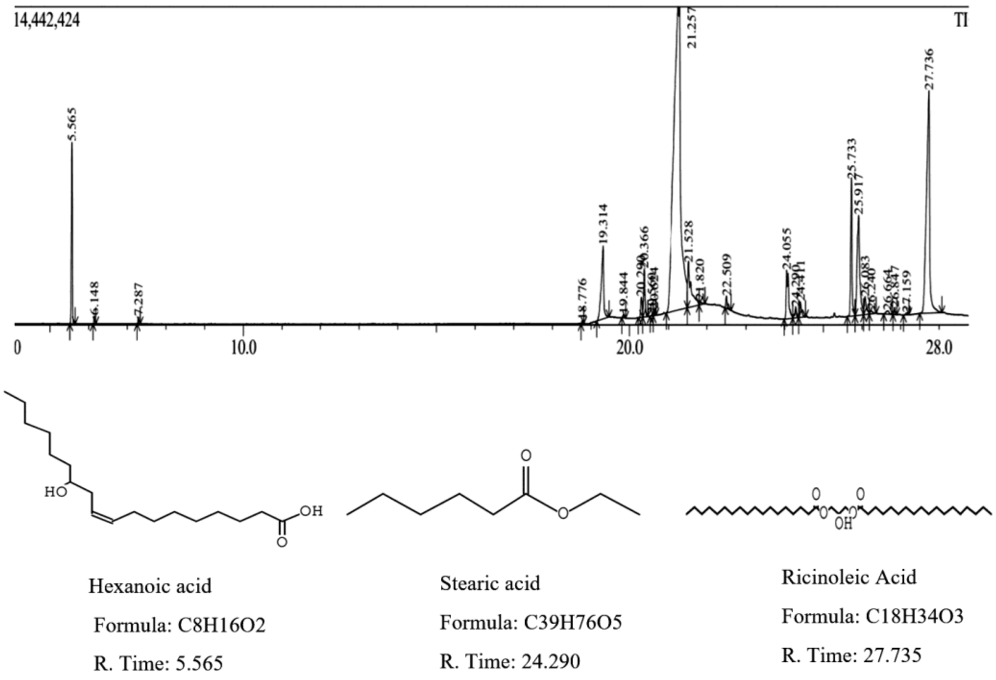

Fig. 4 — GC/MS of bio-oil

vibrations of alkyl aryl ether and secondary alcohol groups. The peaks obtained at 531.27 cm^{-1} correspond to the stretching vibration of halo compound C-Br.

GC/MS analysis

The GC-MS analysis results, illustrated in Fig. 4, identified seven fatty acids in the sample. These fatty acids include hexanoic acid (C8:0), hexadecanoic acid (C17:0), linoleic acid (C18:0), ethyl octadecadienoate (C20:0), myristic acid glycidyl ester (C17:0), stearic acid (C39:0), and ricinoleic acid (C18:0). Each compound was identified based on its retention time and mass spectrum. The results provide a detailed profile of the fatty acids present, showing the diversity of components in the sample. This analysis highlights the complexity and variety of fatty acids in the sample.

Conclusion

Five different solvents acetone, benzene, isopropanol, hexane, and dichloromethane were used to successfully extract seed-oil from *Solanum virginianum* seeds using soxhlet extraction. It was determined that benzene is the optimum solvent, since the bio-oil yield at 80.1°C was 25.34%. To date, many solvents, including have been used to extract the bio-oil. The GC-MS results show the presence of necessary fatty acids in this bio-oil, so, it can be turned into bio-oil. Experimental findings revealed the fundamental characteristics of fuels, including their fire point, flash point, cloud point, pour point, specific gravity, calorific value, and carbon residue. The extraction method was shown to work best when given 3.5 h. The oil has a high concentration of oxygenated species, according to FTIR analysis, and this seed-oil has very low sulphur content, making it environmentally friendly and producing less emissions and less corrosion.

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