Contents list available at IJRED website

International Journal of Renewable Energy Development

Journal homepage: https://ijred.undip.ac.id

Research Article

The feasibility of utilizing microwave-assisted pyrolysis for *Albizia branches* biomass conversion into biofuel productions

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Abstract. The consumption of fossil fuels has caused many challenges, including environmental and climate damage, global warming, and rising energy costs, which has prompted seeking to substitute other alternative sources. The current study explored the microwave pyrolysis of *Albizia branches* to assess its potential to produce all forms of fuel (solid, liquid, gas), time savings, and effective thermal heat transfer. The impact of the critical parameters on the quantity and quality of the biofuel generation, including time, power levels, biomass weight, and particle size, were investigated. The results revealed that the best bio-oil production was 76% at a power level of 450 W and 20 g of biomass. Additionally, low power levels led to enhanced biochar production, where a percentage of 70% appeared when employing a power level of 300 W. Higher power levels were used to increase the creation of gaseous fuels in all circumstances, such as in 700 W, the gas yield was 31%. The density, viscosity, acidity, HHV, GC-MS, and FTIR instruments were used to analyze the physical and chemical characteristics of the bio-oil. The GC-MS analysis showed that the bio-oil consists of aromatic compounds, ketones, aldehydes, acids, esters, alkane, alkenes and heterocyclic compounds. The most prevalent component was aromatic compounds with 12.79% and ketones with 12.15%, while the pH of the oil obtained was 5, and the HHV was 19.5 MJ/kg. The pyrolysis productions could be promising raw materials for different applications after further processing.

Keywords: biomass, *Albizia*, microwave pyrolysis, bio-oil, biochar, biogas

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Received: 30th July 2023; Revised: 10th Sept 2023; Accepted: 17th Oct 2023; Available online: 22nd Oct 2023

1. Introduction

Globally, the demand for clean energy is increasing due to environmental protection and pollution control concerns, primarily related to greenhouse gas emissions. Despite the continued availability of fossil fuels as a source of energy and raw materials for various industries, the era of easily accessible and inexpensive energy from these sources is drawing to a close (Al-Kayiem & Mohammad, 2019). Presently, over 80% of the world's energy is supplied by traditional fossil fuels, such as petroleum, natural gas, and coal (Avargani *et al.* 2022; Nicoletti *et al.* 2015). However, the escalating consumption of these resources to satisfy growing energy demands is projected to rise by 48-56% by 2040 (Khalid *et al.* 2019).

Researchers have been exploring alternative, primarily renewable energy sources for decades in response to these challenges. Biomass is an abundant renewable material with a carbon base that has garnered considerable interest. It comes in various forms and is used for generating power and producing chemicals. The International Energy Agency (IEA) has estimated that biomass could meet up to 27% of the global transportation energy demand by 2050 (Sowmya Dhanalakshmi *et al.* 2022). Because of its many uses, biomass can be transformed into solid, liquid, or gaseous fuels that can be used to produce power, heat, or liquid fuels. Biomass can be converted into fuels using various thermochemical, biochemical, or mechanical techniques (Zhang & Zhang, 2019). Pyrolysis, gasification, and liquefaction are examples of thermochemical conversion processes, whereas fermentation and anaerobic digestion are typical of biochemical ones. Extraction is a mechanical technique that produces oil from the seeds of various biomass crops, such as oilseed rape, cotton, and groundnuts. This technique also provides residue solid or 'cake' appropriate for animal feed besides oil production (Porpatham *et al.* 2012). Among these, pyrolysis has the ability to convert biomass into liquid fuels with the highest calorific values (Mateus *et al.* 2021; Mohamed & Abbas, 2015). Kadlimatti *et al.* (2019) found that the bio-oil derived from food waste was 19.95 MJ/kg, along with Demiral *et al.* (2012); Makkawi *et al.* (2019) that achieved higher heating value of 26.22 MJ/kg and 20.88ff MJ/kg for the produced bio-oil using pyrolysis process respectively. Among all thermochemical processes, pyrolysis is considered the most effective way to convert biomass into energy since it enhances the final products of bio-oil and syngas while limiting the possibility of undesirable oxidation in the pyrolyzer. It is a non-isothermal material degradation that occurs in an inert environment (Abbas 2016; Abbas & Saber, 2018; Gan *et al.* 2018). Furthermore, it has the benefit of processing combinations of various types of biomass without the need for separation or pre-treatment (Abbas & Shubar, 2008).

Compared to conventional pyrolysis techniques, which can be ineffective and energy-intensive, microwave-assisted pyrolysis of biomass has been developed as an alternative technology that uses less time and energy and offers sufficient

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https://doi.org/10.14710/ijred.2023.56907

ISSN: 2252-4940/© 2023.The Author(s). Published by CBIORE

control over the procedure, resulting in more selective product yields (Haeldermans *et al.* 2020).

Microwave-assisted processing involves the rapid heating of microwave-receptive materials using energy-dense electromagnetic waves. Microwaves penetrate materials to cause energetic dipole oscillation and ionic conduction, resulting in heat generation from within, leading to in uniform, selective, and non-direct contact volumetric heating, providing volumetric and uniform heating to the feedstock and generating an outward-flow temperature gradient, which is more efficient and requires less processing time (Foong *et al.* 2022; Ahmed & Theydan, 2014a).

In the past few years, there has been a significant emphasis on utilizing renewable and more cost-effective sources like agricultural waste in conjunction with a microwave production technique that requires minimal treatment time (Duran-Jimenez *et al.* 2017).

Biochar and bio-oil, the products of the pyrolysis process, have versatile applications and are more easily stored and transported compared to pyrolytic gas (syngas). Biochar, a solid biofuel with high carbon content, is environmentally friendly and has numerous applications, such as in soil amendment, carbon sequestration, removal of contaminants, and electrodes for energy storage devices that have been extensively recognized (Ismail *et al.* 2023). Bio-oil, a dark brown viscous organic liquid, has various benefits as an alternative to fossil fuels and in biochemical and pharmaceutical industries due to its chemical composition. (Nishu *et al.* 2020; Vichaphund *et al.* 2019). Enormous type of biomass can be utilized as a source of biofuel, such as food and feed grains (Nonhebel & Kastner, 2011), lingo-cellulosic biomass (Yogalakshmi *et al.* 2022), forest biomass(Wang *et al.* 2020), industrial and municipal waste (Greinert *et al.* 2019) and algal biomass (Al-Yaqoobi *et al.* 2021; Al-Yaqoobi & Al-Rikabey, 2023). *Albizia lebbeck (A.L.),* a medium to large tree from the Fabaceae family, is commonly planted alongside highways for aesthetic purposes and to provide shade. It is native to tropical Africa, Asia, and northern Australia (Ahmed & Theydan, 2013).

The traditional pyrolysis process of *Albizia* has been investigated by different researchers, such as Abiodun Oluwatosin *et al.*(2022) who used a thermal reactor made up of a heating tank where *Albizia zygia* saw dust was pyrolyzed. Also Sowmya Dhanalakshmi & Madhu (2019) used a fixed bed system developed for biofuel production from *Albizia* wood. In contrast, Sowmya Dhanalakshmi *et al.* (2022) used a fluidized bed reactor as a flash pyrolysis of the same material. The bio-oil produced by these operations has some common qualities like higher oxygen, low pH with a high viscosity and low heating value.

The current research focuses on the assessment visibility of microwave-assisted pyrolysis using *Albizia branches* as a potential candidate to generate renewable energy since the feedstock is widely available in Iraq, within reach and very cheap. To the best of our knowledge, using microwave pyrolysis of *Albizia branches*, as well as exploring the feasibility of this process in terms of time and efficiency, and the characteristic properties of the biochar, bio-oil and bio-gas obtained using this technique, has not been conducted before. The subject of this work is to examine the factors affecting the production of biochar, bio-oil and bio-gas through the microwave pyrolysis process, including experimental time, microwave power, material weight and particle size. Moreover, this paper explored the characterization of the liquid and gas produced through the process, whilst another research paper will focus on the specific analysis of biochar with and without the utilization of catalysts.

2. Experimental work

2.1 Material preparation

Albizia trees are a prevalent plant species found within the University of Baghdad in Baghdad, Iraq. Branches were gathered from there, washed with distilled water and dried under 100°C for a day using an oven dryer (inside, Italy). After that, the dried branches were crushed using a coffee grinder (clatronic, Germany) and the resulting particles were separated into three size groups (<500 μm, 500 μm-1 mm, and 1-1.5 mm).

2.2 Pyrolysis Experiment Procedure

A series of experiments were carried out using the experimental setup depicted in Fig.1. The modified microwave oven (Samsung, 24 L, China) with seven power levels (100, 200, 300, 450, 600, 700, and 800 W) was utilized. A cylindrical Pyrex glass reactor served as the pyrolysis reactor and has a diameter of 5 cm and a height of 17 cm. The reactor was connected to an inlet tube for introducing inert N2 gas (98% purity) and an outlet tube to direct the generated pyrolysis gases to a condensation unit consisting of a three-glass cylinder maintained at -15°C. A third tube housed a K-type thermocouple to monitor the reactor's internal temperature. The non-condensed gases were analyzed using a BIOGAS 5000 gas analyzer and released into the atmosphere. The bio-oil and bio-gas obtained in the process were collected and weighed, and bio-gas weight was found by difference. The yield of bio-oil, biochar and bio-gas was calculated as per the Equation below:

$$\mathrm{Y(o,c,g)} = \frac{W\mathrm{o,c,g}}{\mathrm{W_{Biomass}}} * 100$$

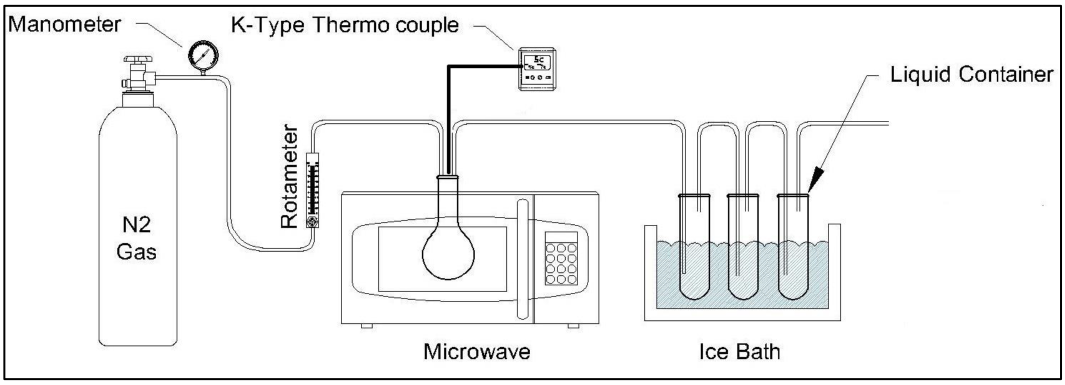

Fig. 1 Schematic diagram of microwave pyrolysis process system

Table 1
Comparative study of the yield of bio products using Albizia tree by different pyrolysis process

Sources	method	Condition	Yield %
	Bio-oil from pyrolysis of Albizia		
Current research	Microwave pyrolysis	20 g, 20 min, 450 W	76%
(Sowmya Dhanalakshmi & Madhu, 2019)	Fixed bed pyrolysis	100 g, 60 min, 500 °C	52.67%
(Abiodun Oluwatosin *et al.* 2022)	Fixed bed pyrolysis	450°C	5.84%
(Sowmya Dhanalakshmi *et al.* 2022)	Flash pyrolysis	450°C, 25 g/min	43.2%
	Biochar from pyrolysis of Albizia		
Current research	Microwave pyrolysis	5 g, 20 min, 300W	70%
(Sowmya Dhanalakshmi & Madhu, 2019)	Fixed bed pyrolysis	100 g, 60 min, 350°C	41.4%
(Sowmya Dhanalakshmi *et al.* 2022)	Flash pyrolysis	350°C	39.1%
	Bio-gas from pyrolysis of Albizia		
Current research	Microwave pyrolysis	5 g, 20 min, 700 W	31%
(Sowmya Dhanalakshmi *et al.* 2022)	Flash pyrolysis	550°C	40.2%

where W_{Biomass} is the weight biomass before pyrolysis (g) and Wo,c,g is the weight of bio-oil and biochar obtained from the pyrolysis process (g).

Initially, varying amounts of feedstock (5 g, 10 g, 15 g, and 20 g) were added to the reactor, with biomass particle sizes ranging from (<500 μm, 500 μm-1 mm, and 1-1.5 mm). Then, inert N_2 gas was introduced into the system at a flow rate of 1 L/min for 15 min before starting the experiment to ensure an oxygen-free environment. The microwave was then activated at a fixed power level.

2.3 Bio-oil analysis

The physical properties of bio-oil, such as viscosity, density, acidity and heating value, were analyzed using different standard methods. The viscosity was determined by a viscometer (Cap 2000, USA) viscometer. The density of the oil was determined by measuring the weight of a known volume. A pH meter (Starter 2000, USA) was utilized to determine the acidity. Finally, a bomb calorimeter (CAL3K-AP, South Africa) was used to measure the heating value of bio-oil.

Fourier transform infrared spectroscopy (FTIR) (Tensor 27, Germany) was used to identify a sample's functional groups and chemical bonds. In contrast, gas chromatography-mass spectrometry (GC-MS) Agelint (7820A, USA) is used to detect chemical compounds presented in bio-oil. There is the provision of an HP-5ms capillary column in the system. Helium (99.999% purity) is used as a carrier gas. The bio-oil sample was prepared by diluting it with hexane, and the volume of the injected sample was 1 μL. The temperature of the oven was initially set at 50°C for 3.5 min in the system program, then it was raised by 4°C /min. to 180°C and held for 5min. The injected and detector temperatures were maintained at 250°C and 230°C, respectively.

3. Results and discussion

3.1 Pyrolysis experiment

3.1.1 Effect of time

The quantity and quality of the products obtained from biomass conversion in microwave pyrolysis are affected by experimental time (or reaction time). The effect of time on pyrolysis productions was investigated in the time range of 5 min - 20 min with different power levels (300 W, 450 W, 600 W and 700 W) using 5 g of biomass with a particle size of <500 μm.

The results show that the bio-oil produced increased steadily with the augment of experimental time for all the power levels until it reached a higher percentage at 20 min. For

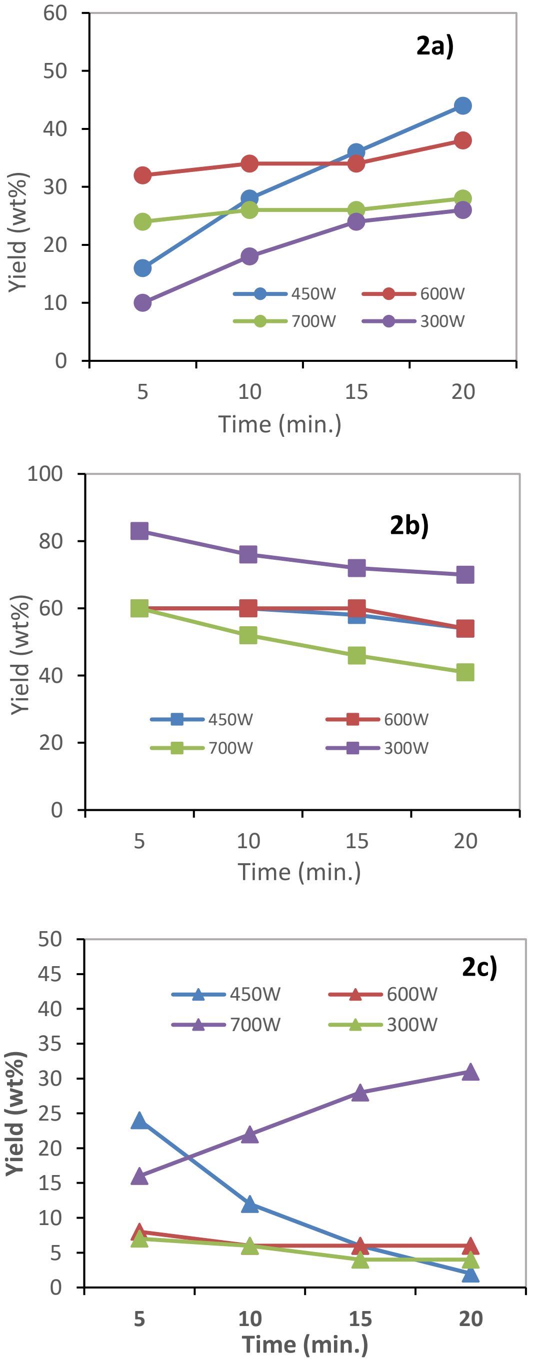

Fig. 2 Effect of time on a) bio-oil yield b) biochar yield c) bio-gas yield.

instance, as demonstrated in Fig. 2a, the bio-oil yield was 10% at 5 min and 300 W, and it was higher by 16% at the end of 20 min. Moreover, as the power was raised to 450 W, the yield increased from 16% to 44% when the experimental duration increased from 5 min to 20 min. At higher power, the same response was also obtained where the oil yield increased gradually at power between 300-400 W due to the gradual increase in temperature. However, at high power levels, the increment in oil yield from the first 5 min until the final experimental time was insignificant.

On the other hand, it is notable that the biochar yield decreased slightly with time in all adopted power levels. Figure 2b indicates that at a power of 300 W, the char yield descended from 83% to 70% with the progression of experimental time from 5 to 20 min. A comparable effect appeared with all power levels, such as at a higher power of 700 W, the char yield decreased from 60% at 5 min to 41% at the end of the experimental time.

Furthermore, it can be noticed from Fig. 2c that at a low power level of 300 W, the gas yield is reduced slightly from 7% to 4% when time increases from 5 min to 20 min. However, the response reversed as the power elevated, where at the power of 700 W, the gas yield increased from 16% to 31% in 20 min of experiment time, hitting the maximum gas yield of 31% at the power of 700 W and experimental time of 20 min. The biogas obtained consisted of CH4 of 1.6% and CO2 of 4.9%, with a large amount of inert gas N_2 and other unaccounted-for gases.

Shorter residence times may lead to incomplete pyrolysis, resulting in lower bio-oil and biogas yields and a higher proportion of biochar. On the other hand, excessively long residence times can cause the volatile components to undergo secondary reactions, such as cracking, polymerization, and condensation, which can reduce bio-oil yields and degrade their quality (Mahmoud Fodah *et al.* 2021). Moreover, longer experimental times can also promote the formation of unwanted products, such as tar and coke, which can affect the efficiency of the process and the quality of the obtained products. In contrast, optimizing the residence time can enhance the selectivity of the desired products, improving the overall efficiency of the microwave-assisted pyrolysis process.

3.1.2 Effect of microwave power

The effect of microwave power on biomass pyrolysis has been studied extensively by many researchers, stating significant impacts on the yield and quality of the products obtained. The power level effect on the pyrolysis process production is shown in Fig. 3.

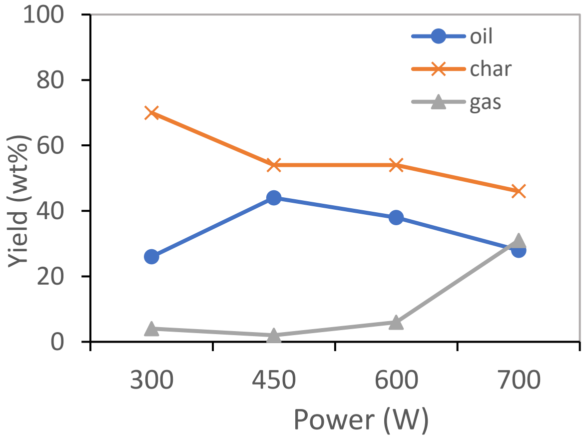

Fig. 3 Relation of power with the yield of bio fuel.

In the same condition as the previous study of time response, 5 g of raw material was used with a particle size of 500 µm, while the power levels were 300 W, 450 W, 600 W and 700 W. The data was presented at a duration time of 20 min of pyrolysis.

The results presented in Fig. 3 demonstrated that the augmentation of microwave power resulted in an increase in the production of bio-oil from 26% to 44% when the power increased from 300 W (350°C) to 450 W (450°C), but then decreased to 38% and 28% at the power 600 W (580°C) and 700 W (650°C) respectively.

On the other hand, the char yield decreased dramatically from 70% at 300 W to 54% at 450 W. The results also revealed that when the power was 600 W, the presence of char levelled off. While gradually decreased to 41% when the power increased to 700 W, which could be attributed to the fact that the rising of microwave power increased the temperature of the reaction, causing a further degradation in the biomass, which leads to a more efficient breakdown of the complex structures in the feedstock and enhanced release of volatile components (Ahmed & Theydan, 2014b; Demirbas 2004).

Consequently, the produced bio-oil reaches a maximum peak of 44% at a power of 450 W, corresponding to the increase in temperature during the reaction with the power raising. After that, the yield dropped as the power rose from 600 to 700 W due to the secondary reactions occurring at higher power levels, where the gas yield increased from 6% to 31% by increasing the power from 600 W to 700 W.

It was feasible that the maximum yield of biochar of 70% was achieved at the power of 300 W, while the maximum bio-oil yield of 44% appeared with the power of 450 W, and at the higher power level of 700 W, the gas yield was reached its higher percentage of 31%.

3.1.3 Effect of biomass weight

Generally, heat transfer in the microwave pyrolysis process is greatly enhanced with the biomass weight increase. The material weight can impact the heat transfer, temperature distribution, and overall biomass conversion efficiency. Figure 4 below shows the relation between weight increase and biomass conversion production. The data exhibited in Fig. 4 were at a power level of 450 W, an experimental time of 20 min with different material weights ranging between 5, 10, 15, and 20 g.

Firstly, the bio-oil production was highly improved from 46% while the material weighed 5 g to 76% when the weight was

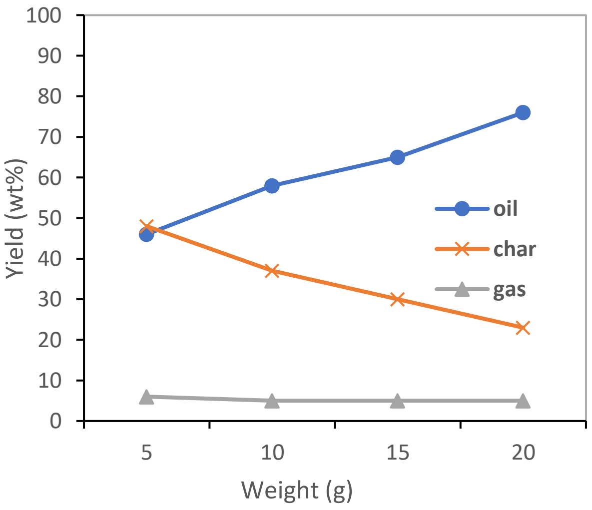

Fig. 4 Effect of material weight on bio fuel producing.

20 g. For the char product, it could be found that because of the increase in potential heating, the yield steadily decreased from 48% to 23% when the material changed from 5 g to 20 g. Finally, the gas response shows that it doesn't affect my weight increasing and still 6% to 5% while the weight changes.

When the material weight is too low, the microwave energy may not be efficiently absorbed, leading to uneven heating and lowering conversion of biomass, which promotes the char product. Conversely, when the material weight is too high, the microwave energy may penetrate the biomass effectively due to higher potential heating, resulting in a lower biochar yield and a higher bio-oil yield. Additionally, excessive biomass feedstock can cause heat accumulation and hot spots in the reactor, which lead to secondary reactions, such as cracking, polymerization, and condensation, which can reduce bio-oil quality. Thus, optimizing the material weight is essential for achieving efficient biomass conversion and obtaining high-quality products.

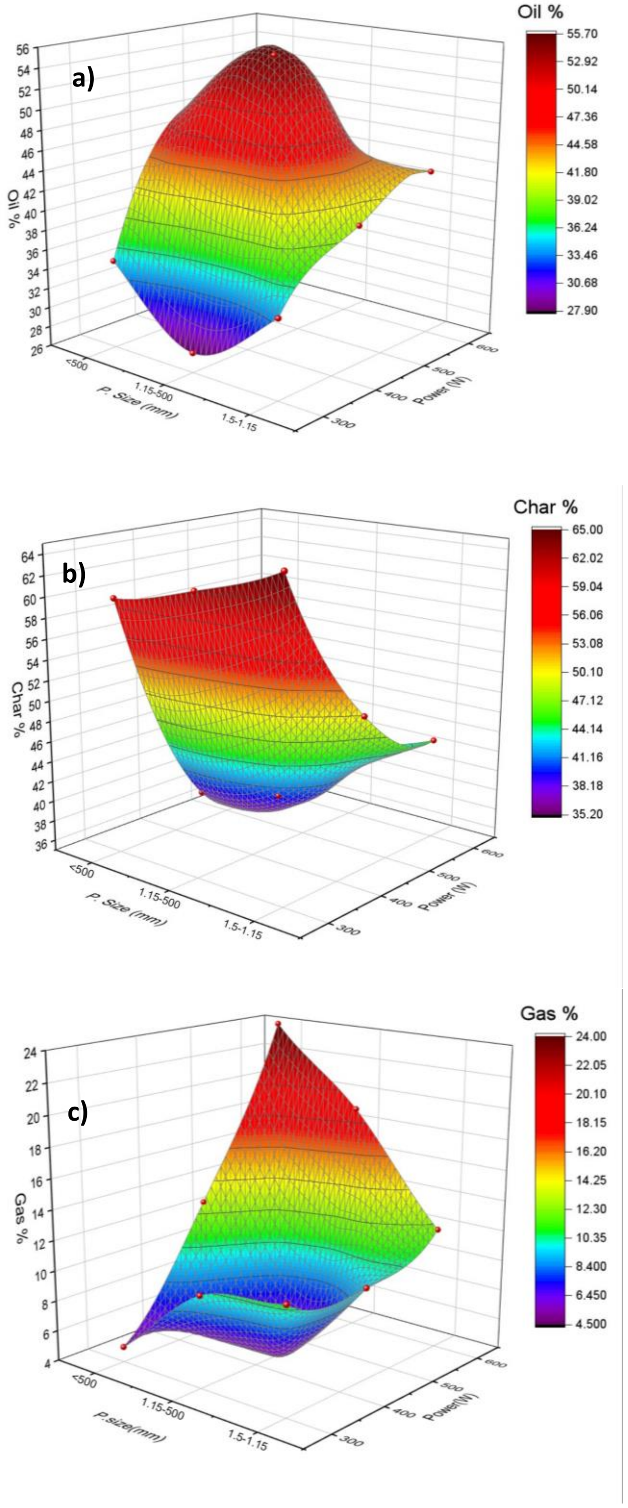

Fig. 5 (a) Interaction of particle size and power on bio-oil production, **(b)** Interaction between particle size and power on biochar production, **(c)** Interaction between particle size and power on gas production.

3.1.4 Effect of particles size

The effect of particle size and the interaction of particle size with power level on the microwave-assisted pyrolysis of biomass is another crucial factor that influences the yield and quality of the products obtained. Figure 5 shown the effect of different particles size from 1.5-1 mm, 1 mm-500 μm and less than 500 μm, at power level of 450 W with constant weight 10 g, and for time of 15 min.

The influence of particle size on biomass conversion production changes with the power level variation; this interaction between particle size and power is shown in Figs.5a, 5b, and 5c below. It can be noticed that microwave pyrolysis enables the selective production of the three different biofuels by making a few adjustments to the operation conditions. Figure 5a shows that utilizing a power level of 450 W and medium particle size of 1 mm-500 μm boosts the most significant bio-oil production by about 55%, whilst the lowest bio-oil yield was obtained by adopting lower power levels. On the other hand, the biochar production seems to be promoted by decreasing the power levels, where the biochar production of 60-65% was obtained with all particles size as it has shown in Fig.5b. For the bio-gas produced, it is evident from Fig.5c that gas production can be the primary objective when high power levels and small particles sizes are used, where the yield was 24% at the power of 600 W and particles size was less than 500 μm, while utilizing large particles size eliminates the effect of power where the yield was 12-13% for all tested power levels.

The particles of tiny size may result in excessive heating, leading to secondary reactions such as cracking, polymerization, and charring, which can reduce the bio-oil yield and degrade its quality. Conversely, larger particle sizes may lead to lower bio-oil yield and a high production rate of biochar due to the limited heat transfer and slower heating rates, resulting in incomplete pyrolysis. Larger particles may also increase the residence time of solid material in the reactor, enhancing the possibility of secondary reactions and char formation (Inguanzo *et al.* 2002; Suresh *et al.* 2021).

3.2 Products yield comparative

From the parameters explored for the microwave pyrolysis of *Albizia branches*, it was recorded that the highest bio-oil yield was 76% obtained during 20 min. However, Sowmya Dhanalakshmi & Madhu (2019) used fixed bed pyrolysis and reached the maximum production of 52.67% during 60 min, as shown in Table 1. Also, Abiodun Oluwatosin *et al.* (2022) and Sowmya Dhanalakshmi *et al.* (2022) investigated that the pyrolysis of *Albizia* can produce bio-oil with a maximum yield of 5.84%, 43.2% using fixed bed pyrolysis and flash pyrolysis.

The low power level enhances the biochar production, where 70% was the optimum yield of biochar at a low power of 300 W. While 41.4% and 39.1% were the maximum char yield produced by Sowmya Dhanalakshmi & Madhu (2019) and Sowmya Dhanalakshmi *et al.* (2022) using fixed bed and flash pyrolysis as given in Table 1.

The higher power level improves gaseous yield because of the non-condensable gases. 31% is the highest gas yield produced when the power was 700 W at an experimental time

Table 2
Comparison of physical properties

Feedstock	pH	Viscosity (cSt)	Density (kg/ m^3)	HHV(MJ/kg)
Albizia lebbeck (This study)	5	4.8	1045	19.5
Albizia amara (Sowmya Dhanalakshmi & Madhu, 2019)	3.6	4.2	1050	18.63
Albizia odoratissima (Sowmya Dhanalakshmi *et al.* 2022)	3.6	7.2	1020	18.15
Waste paper (Islam *et al.* 2005)	1.5	20	1205	13.10
Lemon grass (Madhu *et al.* 2017)	4	7.1	1010	17.2
diesel (Prasad *et al.* 2011)	unknown	2.85	830	44.5

of 20 min using 5 g of biomass Sowmya Dhanalakshmi *et al.* (2022) used flash pyrolysis to produce 40.2% of gaseous fuel.

Microwave pyrolysis surpassed the other traditional pyrolysis processes in terms of oil, char, and gas obtained and the time required for accomplishment by choosing the appropriate operation conditions.

3.3 Bio-oil analysis

3.3.1 Physical analysis of bio-oil

The physical properties of the bio-oil obtained from microwave pyrolysis of *Albizia* and its comparison with other bio-oil produced from different pyrolysis processes are given in Table 2. It can be noticeable that the density of the bio-oil at 35°C was 1,045 kg/m^3, which is higher than the fast diesel fuel that used to be around 780 kg/m^3 (Mujtaba *et al.* 2021)

Furthermore, the fuel mixtures exhibit resistance to flow and its measurement in viscosity units. It is a significant factor in demonstrating the ability for the mass transfer and metering required for engine operation. The higher the viscosity, the lower the volatility and the poor atomization of oil (Sivaramakrishnan & Ravikumar, 2011). The viscosity of the bio-oil obtained was 4.8 cSt at room temperature. While the acidity of the bio-oil at room temperature was 5. The pH value of the obtained bio-oil plays a crucial role in biofuel characterization, where its effectiveness relates to the potential damage of tanks in storage and transport. The acidity of the bio-oil is influenced by various factors, including the specific biomass utilized in its production. According to available literature, the pH of most bio-oils falls within the range of 2-4. However, specific biomass sources, such as rice straw and wheat straw, can yield pyrolysis oils with higher pH values exceeding 4 (Bardalai & Mahanta, 2015).

The higher heating value (HHV) obtained by using a bomb calorimeter was 19.5 MJ/kg, which is higher than that obtained by Sowmya Dhanalakshmi & Madhu (2019) and Abiodun Oluwatosin *et al.* (2022), the HHV of the obtained bio-oil was 18.63 MJ/kg and 18.15MJ/kg, which produced by pyrolysis using fixed bed reactor and flash pyrolysis by using fluidized bed reactor for the same feedstock material. Comparatively, the bio-oil produced from microwave pyrolysis has a higher yield than other pyrolysis methods.

3.3.2 Chemical analysis of bio-oil

Table 3 provides a list of 27 different compounds identified in the bio-oil, along with their retention times (RT), area percentages (Area %), compound names (ID), and Chemical Abstracts Service (CAS) numbers.

The analysis of the GC mass results shown in Fig. 6 reveals that the bio-oil is a complex mixture of various organic compounds. The most abundant compound found in the bio-oil is Phenol, 2-methoxy- with an area percentage of 11.2% and 2-

Table 3
GC-MS analysis of pyrolysis oil

RT	Area%	ID	Cas
4.028	1.82	2-Cyclopenten-1-one, 2-methyl-	001120-73-6
4.132	5.05	3-hexene	000592-47-2
4.357	3.62	2-Cyclopenten-1-one, 2-hydroxy-	010493-98-8
4.764	2.55	2-Butanone, 1-(acetyloxy)-	001575-57-1
4.859	0.98	2-Cyclopenten-1-one, 3-methyl-	002458-18-1
5.214	2.23	Phosphonic acid, (p-hydroxyphenyl)-	33795-18-5
5.405	5.64	4-Heptanone	123-19-3
5.673	0.8	Methanesulfonic acid, methyl ester	66-27-3
5.863	9.52	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	80-71-7
6.296	2.46	2-Cyclopenten-1-one, 3-ethyl-2-hydroxy-	21835-01-8
6.296	2.46	Benzene, 1-fluoro-2-methoxy-	321-28-8
6.625	1.15	2,4-Heptadienal, (E,E)-	4313-03-5
6.625	1.15	2-Ethylcyclohexanol, heptafluorobutyrate	959079-92-6
6.833	11.2	Phenol, 2-methoxy-	90-05-1
7.058	6.25	Pentanal	110-62-3
7.361	2.62	2-Cyclopenten-1-one, 3-ethyl-2-hydroxy-	21835-01-8
7.759	1.93	1,3-Heptadiene, 5,5-dimethyl-	24618-86-8
8.027	1.18	Borane carbonyl	13205-44-2
8.607	3.22	Creosol	93-51-6
9.144	1.88	Methacrylic acid, ethyl ester	97-63-2
10.07	1.93	Resorcinol, 2-acetyl-	699-83-2
10.07	1.93	Phenol, 4-ethyl-2-methoxy-	2785-89-9
10.728	3.28	Phenol, 3,5-diethyl-	1197-34-8
11.316	8.72	Phenol, 2,6-dimethoxy-	91-10-1
11.316	8.72	Benzene, 1-methoxy-2-(methylthio)-	2388-73-0
12.822	1.89	Benzoic acid, 4-hydroxy-3-methoxy	121-34-6
12.822	1.89	2-Cyclopenten-1-one, 2-methyl-	520-45-6

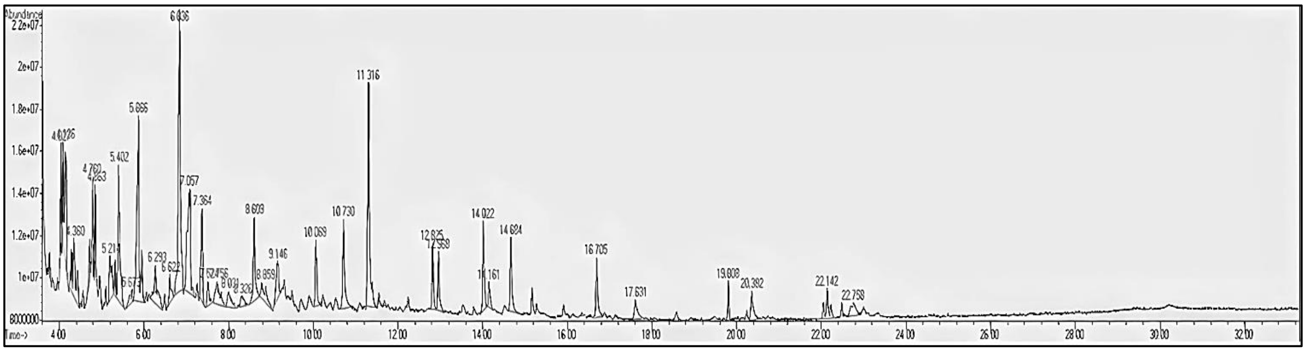

Fig. 6 GC-MS spectra of bio- oil.

Cyclopenten-1-one, 2-hydroxy-3-methyl- with 9.52% area. Phenol 2-Methoxy was also found by Sowmya Dhanalakshmi & Madhu (2019) and Lyu *et al.* (2015) which is a pale yellow aromatic oil typically derived from wood creosote, is employed as a precursor for various flavoring substances such as eugenol. Other compounds with a significant presence in the bio-oil include Phenol, 2,6-dimethoxy- or Benzene, 1-methoxy-2-(methylthio)- with an area of 8.72%, which is the maximum percentage of bio-oil compounds. It can be seen that the bio-oil produced has a high content of aromatics compounds, about 12.97%, such as phenolic compounds and ketones, and about 12.15%, such as 2-Butanone. Also, alcohols (8.8%), Aldehydes (6.16%), a small portion of Acid (4.61%), Esters (4.47%), Heterocyclic compounds (5.83%), as well as Alkenes and Alkanes have (2.55%), (1.67%) respectively.

The presence of the phenolic compound in high concentrations in the bio-oil makes it preferable and suitable for many applications depending on the phenol type, such as fine chemicals, pharmaceuticals, food processing, and resin manufacturing (Kim 2015).

These findings align with previous studies on the composition of bio-oil produced from different pyrolysis processes of *Albizia*. For instance, Sowmya Dhanalakshmi & Madhu (2019) found two significant peaks in the bio-oil: acetic acid and 2-methoxy phenol, with an area percentage of 37.34% and 6.75%. In contrast, the most abounded compounds that appeared with Abiodun Oluwatosin *et al.* (2022) were ethanol, isobutanol, 3-Pentanol, Butan1-ol, 2-mthylbutan-1-ol and 3-methylbutan-1-olol. Furthermore, Sowmya Dhanalakshmi *et al.* (2022) showed that the bio-oil contained more phenols at 36.42%. The primary composition of bio-oil produced from all types of pyrolysis processes for *the Albizia* tree consists of a complex mixture of various organic compounds, including phenolic compounds, ketones, aldehydes, and acids.

3.3.3 FTIR analysis of bio-oil

Fourier Transform Infrared Spectroscopy (FTIR) is a powerful analytical technique that can help identify a sample's functional groups and chemical bonds. It can be noticed from the analysis of the bio-oil sample in Fig. 7. that a clear peak of O-H stretching vibrations appears at 3363.30 cm-1, which is represented by the presence of Phenols, Alcohols, water and acids such as Phenol, 2,6-dimethoxy-, and alcohols present in the bio-oil, also the Ketones, quinone and aldehyde groups is indicated by the absorbance peak C=O stretch vibration at 1709.02 cm^{-1},1640.78 cm^{-1} and1515.89 cm^{-1}, for instance, 1,2-Cyclopentanedione, 3-methyl- and 1,3-Cyclopentanedione are ketones found in the

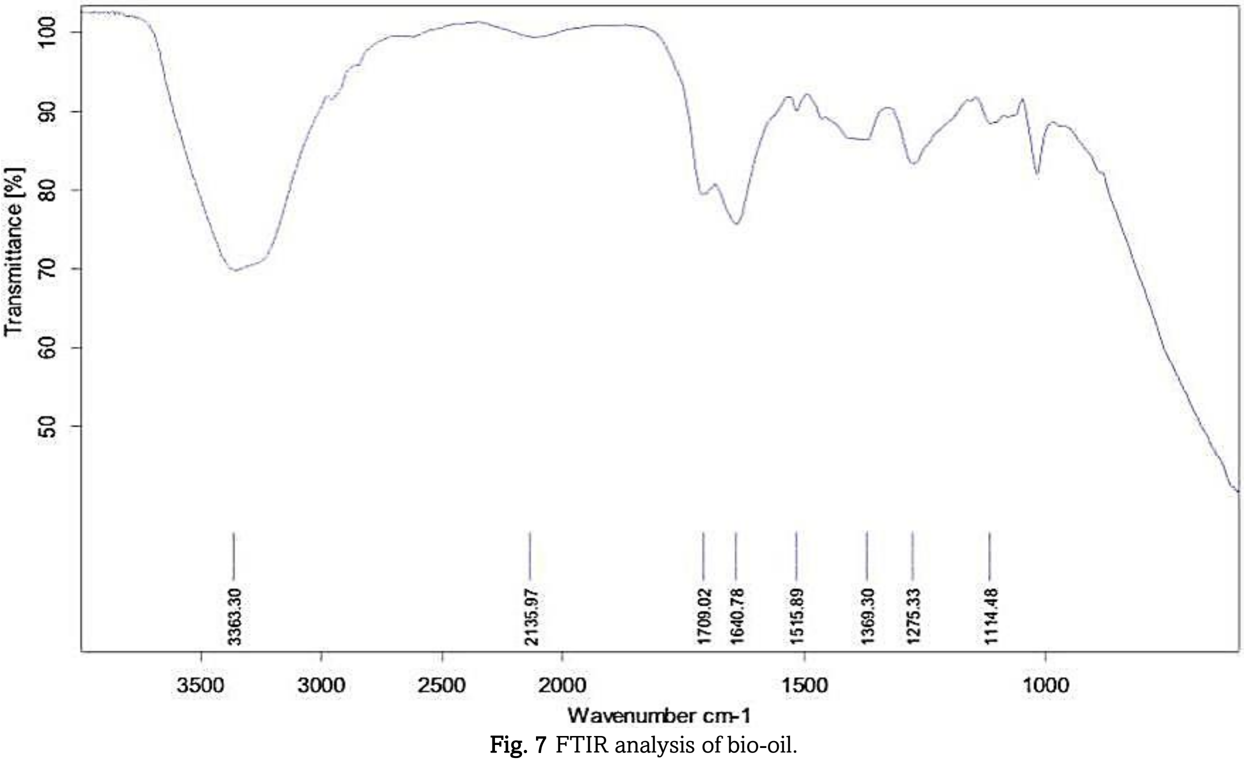

Fig. 7 FTIR analysis of bio-oil.

bio-oil. Comparable peaks have also been identified in the pyrolysis of *Albizia* palm shell and apricot seed kernel (Abnisa *et al.* 2011; Sowmya Dhanalakshmi & Madhu, 2019). CH bending at 1,369.30 cm^{-1} indicates the presence of alkane groups. While C-O stretching vibration 1275.33 cm^{-1} ,1114.48 cm^{-1} indicates the presence of alcohols, esters, and ethers (Madhu *et al.* 2018).

4. Conclusion

In this study, *Albizia branches* were pyrolyzed using a microwave to produce biofuels as an alternative to fossil fuels due to the numerous issues associated with the usage of fossil fuels.

The effects of power levels, biomass weight, particle size, and process duration are the parameters employed in this study. The results showed that the most influential parameter on the yield of the biofuel products was the power, as it was found that low powers promoted the production of biochar, while slightly increasing in power level led to generating a higher bio-oil yield. On the other hand, high power levels are employed to promote the formation of gaseous fuels and reduce the production of solid and liquid fuels. The other parameter that affected the product's yield was the time consumption, where the bio-oil yield reached its maximum value at the end of 20 min. Conversely, biochar yield was still reducing as time increased from 5 to 20 min.

Furthermore, the gas product starts to decrease with the low power levels when time increases, and the response is reflected with the higher power level. The results also revealed that the biochar yield improved while the particle size increased with all power levels. The last parameter is the biomass weight. Bio-oil yield enhanced as the biomass weight increased from 5 to 20 g; by contrast, biochar decreased as the weight increased. Furthermore, Gas products nearly levelled off with this variable. The bio-oil obtained has a calorific value of 19.5MJ/kg and pH of 5, while the GCMS and FTIR analysis revealed that the liquid fuel is made up of a variety of chemical substances, the most significant of which are light and aromatic substances such as phenolic and ketone chemicals make up 12.15 % of it. The presence of phenolic compounds increases the effectiveness of the fuel since it can be utilized as a raw material by the pharmaceutical, chemical, and food segments.

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