Analysis of different date palm parts for char production

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Abstract. The purpose of this study is to investigate the suitability of date palm tree’s different parts residues for char production. There is a arising interest in producing renewable energy form different type of waste, one of the most important sources are agriculture waste since it’s a continuously demand-based industry with a future insight. Iraq is one of the leading countries that contain the highest number of date palm trees, which lead to a high amount of unused waste. Different parts of the date palm tree were analysed to understand its potential availability for energy use. The cellulose, hemicellulose and lignin were estimated for the different date palm tree parts. Carbon, nitrogen and hydrogen were also determined and carbon percentage found to promising in all the parts. FTIR and TGA were done with the different parts to detect its chemical bounds and how the mass material changes when applied to heat in a different atmosphere, the thermal decomposition was observed to 600 °C. Heating value was found up to 20.3 MJ/kg. The volatile matter had a range of 75.2 – 82.1 %. According to the data gathered and the tests were done it was found that date palm trunk and stones might be a sustainable source for energy productions.

Keyword: date palm, energy, waste, recycle

1. Introduction

Due to rising energy costs and greenhouse gas emissions, new renewable resources are being chosen to be an alternative material for bioenergy production. Hardwood gathered from natural forests has been used for quite a time now, and other non-wood materials have gained interest. Date palm is one of the most common trees in the Middle East. The date palm tree is mainly used for its fruit and fibre, it has also been used as a construction material [1][2]. Recently it has got the attention to be advised as a natural feedstock for energy production. Residues are often used in several processes as raw materials due to concerns over greenhouse gas emissions and the non-renewable nature of fossil fuels have encouraged important research into the transformation of biomass into biochar, biofuels and other value-added renewable products [3]. Date palm is one of the world’s earliest cultivated trees [4], it also has a long survival history. The date palm tree has a very rough body; it has the availability to grow after being exposed to unnatural circumstances along with the ability of survive in harsh arid environments [5]. It has been found that there are about 120 million date palm trees have existed in the world; each tree generates around 20 kg of dry leaves annually while date pits account for almost 10% of date fruits. A varied range of chemical and thermal technologies have been applied to the sustainable application of date palm biomass to study its changed characteristics [5]. It has been valued that biomass resources, including resources converted to pyrolyzed energy sources, could provide up to 25% of the world’s primary energy demand by 2050 [6]. The Zahdi cultivar is one of the most popular date palms and is widely used in date syrup production. The lead to a massive amount of date palm waste like date stones, leaves and trunk that are cropped annually [6].

Many factors affect the valuable properties of biomass feedstock that can be used for fuel. The higher heating value may be achieved from the residue with higher lignin content and extracts [7,8]. Wood and non-wood materials used for energy production are preferred to have lower ash content [8,9]. The general energy production yield can be described and affected by many factors, one of them is the heating value that will be calculated in this study.
The chemical energy of the biomass can be described by the volatiles and fixed carbon contents [10]. The volatile matter content is the ratio that is driven-off as a vapour or gas by heating the fuel to 950°C, while the remaining is fixed carbon, eliminating the moisture and ash content. These forms describe the proximate analysis, which is considered a suitable method to define and calculate the heating values of biomass. In earlier work by [10], the characteristics and heating values of a Sukkari cultivar date palm were studied.

The main goal of this paper is to study the expected energy production from different parts of the date palm and discuss its possibility to be transformed into a value-added product.

2. Methods and Materials

2.1. Date palm tree waste

Date palm residues were taken from three date palms of Zahdi cultivar for analysis. The age of date palm ranged between (10-32) years. The three trees were harvested on a farm located in Alkhargoulia, approximately 20 km from Baghdad centre. The location has the following characteristics: 33°17 N latitude and 44°33 E longitude, temperature statistics from the nearest weather station ranges between 16.06°C in winter and 30.78°C in summer, 17.68 mm average annual rainfall. The total area of the land is 1.75 ha, but the area with plants date palm is 1 ha and contains 100-120 date palm trees. In September 2019 and during the seasonal trimming, palm trunk (PT), palm leaf sheath (PL) and palm leaves (PLL) were collected from each palm tree and weighed as shown in Table 1. Date palm seed was being collected from a private household syrup factory. The remains were air-dried and cut into small particles. A part of the sample was powdered for some tests.

| Tree no. | Trunks diameter (cm) | Palm height (cm) | Frond length (cm) | Fruit weight (kg) |
|----------|---------------------|-----------------|-------------------|------------------|
| 1        | 132.3               | 315.2           | 290.3             | 83.5             |
| 2        | 156.9               | 464.1           | 352.5             | 75.2             |
| 3        | 155.6               | 378.6           | 382.1             | 127.5            |
| Mean     | 148.27              | 385.97          | 341.63            | 95.4             |

The different parts may be referred to by a, b, c and d, which present palm trunk, leaves, leaf sheath and date stones, respectively. As shown in Figure 1.

![Date palm tree residues](image1.png)

**Figure 1:** Date palm tree residues (from left; Trunk (A), Leaves (B) and Stones (C))
2.2. Chemical analysis

2.2.1. Cellulose, hemicelluloses and lignin content. Hemicellulose, cellulose, and lignin content were determined according to the Van Soest method. Samples ash contents were calculated as a percentage of the main amount of the samples based on the dry weight.

2.2.2. Ultimate and proximate analysis

- **CHNO**: The samples were oven-dried at a temperature of 60°C for 15 minutes proximate analysis and the ultimate analysis (carbon, hydrogen and nitrogen percentage rates) was carried using EuroEA 3000 elemental Analyzer.
- **Volatile matter and ash content**: Volatile matter and ash content were estimated, but fixed carbon content was found by differentiating. The average analysis values for the different date palm residues are shown in Table 3.
- **Thermal properties of the date palm residues**: The data which were found in TGA is useful in describing its purity and composition of materials, drying and ignition temperatures of materials and understanding the stability temperatures of the samples. It is also a very important parameter in the design of a reactor for the pyrolysis of material. The TGA was achieved using STA PT-1000 LINSEIS (Germany). The figures present the decomposition of the biomass in the range (0-600°C) in a limited oxygen atmosphere by presenting Aragon through the decomposition process with a 10°C/min heating rate.

2.2.3. FTIR analysis. FTIR spectroscopy is a simple technique used to obtain rapid information about the chemical bonds and describe the structure of the material. One of the greatest advantages of this technique is that virtually any sample in any state may be analysed. FTIR systems have been used in coal science for a number of descriptions and kinetics, in order to understand functional group arrangements.

2.3. Heating value of the sample

The heating value (HV) was determined as an indicator of the fuel characteristics. The heat value of a fuel is the quantity of heat released during its combustion. Also referred to as energy or calorific value. The value was estimated by using the Channiwala formula [8].

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HHV \text{ in MJ/kg} = 34.91 \times C + 117.83 \times H - 10.34 \times O - 1.51 \times N + 10.05 \times S - 2.11 \times Ash
\]

3. Results and Discussion

3.1. Date palm parts chemical composition

The chemical composition of the Zahdi date palm residues compared to Sukkari date palm residues [10] are shown in Table 2.

The cellulose content of the samples ranged between 25 – 35 %. As it can be recognized the Zhadi date palm parts had lower cellulose content than hardwood. These results agree with the conclusions of previous work [10, 12]. Except for the palm leaf, wood and non-wood plants have similar hemicelluloses content, these results also settle with previously reported data [10, 12].

Table (2) also presents the lignin content of the samples, which showed a high percentage when compared to hardwood. The different parts had different compositions; the study was compared with a previous work by [8], where also date palm was investigated but differs in type and country.
Table 2: Zahdi date palm residue chemical composition

| Type         | Feed stock     | Cellulose (%) | Hemicellulose (%) | Lignin (%) |
|--------------|----------------|---------------|-------------------|------------|
| Zahdi:       | Palm trunk (PT)| 34.26         | 29.69             | 36.05      |
|              | Palm leaves (PL)| 25.01         | 32.89             | 42.10      |
|              | Palm leaf (PLF)| 29.21         | 39.76             | 31.18      |
|              | Date palm stone (DPS)| 34.25| 19.28             | 46.33      |
| Sukkarri [9]| Palm trunk (PT)| 39.37         | 30.31             | 30.32      |
|              | Palm leaves (PL)| 47.14         | 16.13             | 36.73      |
|              | Date palm stone (DPS)| 32.77| 30.20             | 37.03      |
| wood [10]    | Hardwood       | 45-50         | 15-35             | 23-30      |

3.2. Date palm parts ultimate and proximate analysis
The analysis of the date palm residues is shown in table (3), there has been found to be some variation between the parts. Palm trunk and date palm stone were found to be most similar to hardwood. The following values were found: volatile matter content ranged from 75.96% for PL to 81.63% of DPS, ash content was found to be ranged between (1.14-8.6%) and fixed carbon content ranged from (11.86-18.85%).

Table 3: Zahdi date palm residues ultimate and proximate analysis compared with Sukkari cultivar and another biomass.

| Type         | Feedstock     | Ultimate Analysis | Atomic Ratio | Proximate Analysis | Ref. |
|--------------|---------------|-------------------|---------------|--------------------|------|
|              |               | C     | H    | N    | O    | H/C  | O/C  | VM   | Ash | FCC |
| Zahdi:       | Palm trunk (PT)| 38.54 | 5.86 | 0.10 | 55.5 | 1.86 | 1.08 | 80.21 | 1.14 | 18.65 |
|              | Palm leaves (PL)| 42.02 | 6.24 | 0.54 | 41.2 | 1.78 | 0.74 | 75.96 | 8.18 | 11.86 |
|              | Palm leaf (PLF)| n.d  | n.d  | n.d  | n.d  | n.d  | n.d  | 2.29  | n.d  | n.d  |
|              | Date palm stone (DPS)| 46.37| 8.06 | 0.01 | 45.57 | 2.09 | 0.74 | 81.63 | 4.6  | 13.77 |
| Sukkarri [9]| Palm trunk (PT)| 44.46 | 5.75 | 0.55 | 49.24 | 1.55 | 0.83 | 78.53 | 3.86 | 17.61 |
|              | Palm leaves (PL)| 46.50 | 5.69 | 0.66 | 47.15 | 1.50 | 0.90 | 74.29 | 15.2 | 10.51 |
|              | Date palm stone (DPS)| 47.14| 6.63 | 0.90 | 45.33 | 1.69 | 0.72 | 83.33 | 1.40 | 14.94 |
| [10] wood    | Hardwood       | 50.8  | 6.4  | 0.40 | 41.8  | 1.51 | 0.62 | 77.3  | 3.4  | 19.4  |

The volatile matter of palm trunk and date palm stone was found to be more than 80%. The portion of volatile matter wood is typically high, 80% of the energy creating in the combustion of volatile matters [13]. Volatile matter is used to define coal rank in the U.S. classification system, it also may have a low ignition temperature.

Fixed carbon values for date palm trunk and date seed were found to similar to hardwood value. The low fixed carbon found in some residues was according to their high volatile matter and indicated that the main part of the residue is consumed in the gaseous state during combustion.
High ash content typically reduces the fuel heating value. Wood biomass ash content usually ranges from 0.08 to 2.3%. The date palm residues were considered by higher ash content [8] than those found in common wood species. Ash content in wood normally does not exceed 1%, but can reach up to 5% in some tropical species [8]. Date palm stone and palm leaves found to have the highest ash content, which may affect the efficiency of energy production.

Date palm trees are known to survive in arid areas, furthermore, more mineral elements for growth have required in comparison with woods, the high ash content may be due to the growth and nutrition status [8].

3.3. Date palm parts thermal properties

The thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) curves for trunk, leaves, leaf and seeds are shown in Figure 2. During stage 1, at low temperature, a loss in moisture content takes place. During stage 2, hemicellulose, cellulose and lignin degradation into volatiles at higher temperatures (205 to 405 °C). Trunk and leaves had somehow similar degradation lines that may be to the hemicellulose and cellulose content converge. This peak-shape may be allocated to the cellulose–hemicellulose, partially overlapping with lignin. But this peak appears at about 25°C below in the case of palm leaves than in the case of the trunk. It directs the existence of the other components in the different residues, which affect the thermal stability of cellulose and hemicellulose [18]. The thermal decomposition of hemicelluloses is known to take place at temperatures ranging from 150 to 350 °C, while cellulose requires a somehow higher temperature, between 275 and 350 °C [14]. Though, lignin slowly decomposes at much higher temperatures ranging from 250 to 500 °C. It is also known that when the T_max, which is the temperature where the sample lost the most weight, it's low, the easier it is to ignite a fuel [15]. Hence, it can be said that all the date palm residues are relatively easier to ignite as fuels. The temperature at which a rapid reduction in the TGA curve is called the ignition temperature was found to be less than 210 °C for trunk, leaves and leaf. As the volatile matter increases, a decrease in the ignition temperature occurs and char becomes more reactive [8]. Date palm stones require a higher temperature to be completely degraded, which may due to their higher lignin content.

The DSC curve describes the flow into a sample measured as a function of temperature or time. Glass transition temperature is described as the temperature at which 30–50 carbon chains start to move. The glass transitions may occur as the temperature of an amorphous solid is increased. From the DSC curve, we may notice that this temperature is found to be at 109.6°C, 84.4°C, 91°C for trunk, leaves and leaf. Also, we may mention that at the beginning of the curve there a separate peak of weight loss, which corresponds essentially to the loss of adsorbed and bound water [19]. While date palm seeds were more complicated and undergo the transition in two temperatures than may be due indicate two separate non-mixed/separated phases. Also, the leaves undergo freedom of motion to naturally arrange themselves into a crystalline form, this took place at 521°C. Date seed (DSC) curve had several peaks, which may be due to seed density and the existence of protein and non-protein components that probably contribute to the thermal denaturation behaviour of the seed [21].

3.4. FT-IR analysis

It is settled that the FTIR method offers good quality infrared spectra of opaque materials such as coal and char. Date palm residue cell walls mainly contain cellulose, hemicelluloses and lignin. Normally, O–H stretching absorption bands (around 3400 cm⁻¹) and C–H absorption bends (around 2927 cm⁻¹), most of our samples have contributions from all these chemical components [21]. So, the functional groups in the print region between 2000-6000 cm⁻¹ always been used to distinguish differences [17]. FTIR bands in the fingerprint region of different date palm remains are shown in figure (3). Bond intensities reveal that the most abundant chemical bonds are O–H, C–H, olefinic C=C and C–O, which is similar to bonds found in maize stalk, rice straw and cotton straw (22). In date palm seeds the N–H bond may be found, the average strength of the vibration of the H-bonded N–H depends on the molecular structure [17]. Most of the C–O bonds found are due to the cellulose, hemicellulose and lignin content.
in the residues. The FT-IR analysis is similar to a study done by [22] where the raw materials have later been converted to successful biochar.

Figure 2: TGA-DSC curves of date tree a) trunk, b) leaves, c) leaf, d) seeds

Figure 3: FT-IR analysis of date palm residues a) trunk, b) leaves, c) seeds
3.5. **Heating value of the date palm parts**

The values of the target sample compared with previous work are shown in Table 4.

**Table 4:** High heating value (HHV) of different date palm residue compared with another biomass

| Type | Feedstock                  | Higher heating value (MJ/kg) | Reference          |
|------|----------------------------|-----------------------------|--------------------|
| Zahdi| Palm trunk (PT)            | 16.66158                    | This study         |
|      | Palm leaves (PL)           | 17.49795                    |                    |
|      | Palm leaf (PLF)            | n.d                         |                    |
|      | Date palm stone (DPS)      | 20.27715                    |                    |
| Sukkari| Palm trunk (PT)         | 18.175609                   | Nasser et al., 2016|
|      | Palm leaves (PL)           | 18.707041                   |                    |
|      | Palm leaf (PLF)            | n.d                         |                    |
|      | Date palm stone (DPS)      | 19.508779                   |                    |
| Hardwood | Hardwood                      | 18.5–21.0                  | Huhtien, 20            |

Familiar biomass fuels reported in previous works; corn grain that is usually used for ethanol production had an HHV of 16.98 [22] and sawdust with a heating value of 18.23 [23], the HVs of the different date palm residues was found to be similar to the species mentioned. Based on the found HVs and compared to other biomass fuels, the results directed that these remains can be considered as a suitable source for energy production.

4. **Conclusion**

The present study studied the suitability of different parts of a date palm tree for char production. The major constituents of date palm biomass are hemicellulose, celluloses and lignin. In addition, date palm residues have low moisture content and high volatile solids content. These factors make date biomass an outstanding waste-to-energy source. Using agricultural waste in energy sectors and environmental science has gained interest in the past few years, many studies have used agriculture seeds or wastes for soil improvements or treatment [25,26,27].

Some of the date palm residues had higher ash content than typical wood species which could be a limiting factor for some energy requirements. Even so, the use of date palm biomass properties could confirm the availability of sustainable energy supplies in the future. From the present study, it can be concluded that date palm residues could be an important and sustainable source for clean and green energy to meet the rising demand taking place in date palm producing countries.

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