



## تأثير عاملي حرارة وزمن عملية التفحيم في بعض خصائص الفحم الحيوي المحضر من قشور قرون الفول السوداني

### Effect of temperature and time factors of carbonization process on some properties of biochar prepared from peanut pods

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#### الملخص

نفذ البحث في مخبر خصوبة التربة وتغذية النبات في جامعة تشرين، على الفحم الحيوي المحضر من الكتلة الحيوية لقشور الفول السوداني، تضمنت التجربة (12) معاملة، مكونة من تداخل أربع مستويات لحرارة التفحيم (350, 450, 550, 650 °C) وثلاث مستويات لزمن التفحيم (15، 30 د، 60 د)، وثلاث مكررات لكل معاملة. بينت النتائج تأثيرات عالية الموثوقية لتأثير عاملي الحرارة وفترة التفحيم في نسبة المتبقي من الكتلة الحيوية بعد التفحيم (الانتاجية)، كما كان هناك علاقة عكسية واضحة بين تركيز الكربون العضوي في الفحم الحيوي وكل من حرارة التفحيم وفترة التفحيم حيث سجلت قيمة الكربون العضوي في نواتج التفحيم أعلى قيمة على حرارة (350 °C) وهي (20.83 g.kg<sup>-1</sup>) وأدنى قيمة على حرارة (650 °C) وهي (13.28 g.kg<sup>-1</sup>) وهذا مؤشر عكسي لاكتمال عملية التفحيم. كما زادت سعة التبادل الكاتيونية للفحم الحيوي مع زيادة حرارة وزمن التفحيم واستقرت هذه النسبة عند الحرارة (650 °C) حيث تراوحت ما بين (168.87-172.52) سنتمول. كغ<sup>-1</sup>، بزيادة مدة التفحيم عن (1/4 الساعة).

**كلمات مفتاحية:** الفحم الحيوي، التفحيم، قشور الفول السوداني، الكربون العضوي، سعة التبادل الكاتيونية.

#### Abstract

This experimental work was carried out in the soil fertility and plant nutrition laboratory - Soil and Water Science Department in Tishreen University, using biochar prepared from the biomass of peanut pods. The experiment included (12) treatments, consisting of (4) levels of carbonization temperature (C), (350, 450, 550 and 650 °C) in combination with (3) levels of carbonization residence time (15, 30 and 60 minutes), in three replicates. The results showed that, there is a highly significant effect for the two factors on the percentage of biochar productivity from the biomass after carbonization, and there is a clear inverse relationship between the (O.C g.kg<sup>-1</sup>) stuck in the biochar and both factors of temperature and carbonization timings, where the value of the stuck (O.C) in the carbonized products

recorded the highest value (20.83 g.kg<sup>-1</sup>), at the lowest tested temperature of (350 °C), and recorded the lowest value (13.28 g.kg<sup>-1</sup>) at the highest temperature of (650 °C), which is a reverse indicator for the degree of completion of the carbonization process. Also, the biochar (CEC), increased with increasing temperature and time of carbonization, where its values stabilized at temperature (650 °C) and recorded (168.87 - 172.52) cmol.kg<sup>-1</sup>, when the time of carbonization, exceeded a ¼ an hour.

**Keywords:** Biochar, carbonization, Peanut pods, Organic carbon, CEC.

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## 1.introduction:

Biochar according to (Lehmann and Joseph, 2009), is a product rich in elemental carbon, resulting from the so-called pyrolysis of organic materials in the absence or limited presence of oxygen, and at relatively low temperatures (less than 700 °C). The two researchers pointed out that this process is similar to the process of formation of energy coal (Charcoal), It does not differ from that except, the process of preparing biochar is done for a purpose to its use as a soil conditioner. Schmidt and Wilson (2014) referred that the thermal processes of biochar that called (pyrolysis), is a composite word derived from the Greek origin, since (pyro) means fire or heat, and (lysis) means dissociation, and in its entirety means the thermal decomposition of the biomass that leads to the formation of biochar, while the basic mineral elements of plant growth remain as part of the molecular structure of biochar, holding it and preventing it from being washed to remain under the influence of the biological secretes of the roots and soil microbes that gradually transform them into available forms to plant. The idea of the biomass carbonization process, to obtain biochar, sparked great interest among scientists who noticed later its ability to improve soil properties and slow the movement of pollutants in it (Claoston, *et al.* 2014), and increase their fertility by reducing the washing and loss of nutrients, such as nitrates and phosphates (Laird, *et al.* 2010), contributing to increased soil adsorption surfaces, as well as many other impact mechanisms. (Glaser, *et al.* 2002). Cimo and others, (2014), indicated that studying the physical and chemical properties of biochar produced at different temperatures can increase understanding of the role and behavior of biochar when treating the soil with this product, but it is necessary to know what happens during the pyrolysis process of organic materials by knowing the structure and characteristics of biochar. Biochar particles contain microscopic crystalline molecules consisting of a large number of mineral carbon atoms that form the aromatic rings, these compounds present as hexagonal rings of carbon atoms linked in form of longitudinal sheets or layers forming what is called biochar or (graphite), with some solid impurities and spaces which in turn form large and small pores between layers and give it a porous bulk, (Brenal, 1924). Pyrolysis breaks down the polymeric chain of the complex structure of the biomass (cellulose, hemicellulose, lignin, fat ...ets), to produce a group of solid products consisting mainly of carbon atoms in the form of crystalline molecules (graphite), in addition to liquid and gas compounds that evaporate or volatilize outside the charred mass leaving what is called biochar with some solid impurities of calcium carbonate and mineral elements, in the presence of little or no oxygen, as the carbonization heat plays a major role in the development of the biochar tissue structure by rearranging the crystalline structure of the solid components (Asadullah. *et al.*, 2011). The chemical and physical properties of biochar differ greatly, depending on the nature of the raw materials and the conditions of the carbonization process itself, it has become known that the carbon content and its aromatic or cyclic composition increases with the increasing temperature of carbonization. (Ascough, *et al.*, 2011). Many researchers have found that

increasing the temperature of the carbonization process, causes an increase in the specific surface area of biochar particles (Yuan, *et al.*, 2011; Zhao, *et al.*, 2017). Sohi and others (2010), indicated that the different biomass sources for the raw materials of biochar, and the temperature during the carbonization process affect the distribution and size of the porous structure of the produced biochar and thus affect its absorptive and hydrous properties. Also, Gaskin and others (2008), found that the carbonization temperature of (500 °C) produces biochar more rich in nutrients (P, K, Ca, Mg), with (78%) elemental carbon content. Similarly, Gai and others (2014), found that the production of biochar and its nitrogen, hydrogen and oxygen contents decrease with an increase in the carbonization temperature from (400 -700 °C), while its ash, pH and elemental carbon contents increases with increasing temperature, and all biochar treatments were able to adsorb nitrate and ammonium in line with the Freundlich model. Biochar made from corn cobs achieved the first rank in terms of its ability to absorb ammonium and nitrate, then biochar made from peanut husks in the second rank and in the third biochar made from wheat straw, because corn cobs had higher specific surfaces area. While Sun and others (2011), found that, biochar made from poultry manure has a higher specific surface area than biochar made from wheat straw, even they were produced at the same carbonization temperature of (400 °C). Keiluweit and others (2010), indicated that the raw material from which biochar is made, affects its nutrient content to the same degree as the conditions of the carbonization process. They found that the low amount of nitrogen in the biochar produced from turnip stems was due to its low concentration originally in turnip stems. At the same time raising the temperature of pyrolysis of the biomass of turnip stems from (200 to 700 °C), contributed in increasing the elemental carbon content in the biochar from (13.3 to 80.2 %), reducing the percentage of impurities, as hydrogen decreased from (5.9 to 1.3%) and oxygen from (39.5 to 5.3%). Cao and Harris (2010), found that the decrease in the biochar productivity with the high carbonization temperature is caused by the loss of non-metallic elements such as (H, N, S, O), which volatilize with the increase in the carbonization temperature, while the minerals in the biochar during the carbonization process are concentrated on the form of silicate, metal oxides and carbonates and form the ash and as a result the pH of the biochar usually tends to be alkaline. In the same context, (Keiluweit, *et al.* 2010), found that, the alkalinity of the biochar is caused by the high contents of alkali minerals carbonates in its ash. It was mentioned by Schmidt and Wilson (2014), that, during the pyrolysis of the biomass at a temperature between (350 to 450 °C), a groups of organic chemicals are produced and some of them remain stuck in the pores of the biochar structure, this groups may have a role in stimulating the plant's internal immune system, which increases its resistance to pathogens. Different point of view by other researchers such as Gell and others (2011), found that low temperature produces more toxic biochar for the plant due to the continued presence of tar and other toxic plant compounds in biochar. Claston and others (2014), found a decrease in yielding of biochar, prepared from apple tree branches at different temperatures (350, 500, 650 °C) due to the decrease in the residual impurity percentage of hydrogen, organic carbon, and nitrogen that accompany the elemental carbon with increased carbonization temperature, where the biochar percentage recorded about (51 %) at a temperature level of (350 °C), but it decreased to (29 %) at a temperature of (650 °C), and these temperatures contributed to creating new microscopic pores, increasing the unit volume of microscopic pores, and volatilizing the tar, as the carbonization process progresses. Also, Ahmad and others (2012), see that the carbon structure of the biochar becomes more organized and porous and the morphological form of biochar becomes similar

to bee's wax. In a comparison study by Lawrinenko (2014), indicated that, the biochar produced from three sources of biomass, alfalfa, corn and cellulose, at a carbonization temperature (500 and 700 °C), have relatively higher levels of (AEC), when the carbonization temperature increases with lower pH level. Lawrinenko and Laird (2015), found that there are an anions adsorbing sites contribute to increase the (AEC) and do not depend on the changes of (pH) values, these sites are caused by the formation of rings or structures that contain oxonium in its composition during the carbonization process. Which means, according to their opinions, the ability to control increasing the anion exchange capacity of the resulting biochar along with the high cation exchange capacity, which allow increasing its potential application areas, such as agricultural, horticultural, water purification and environmental protection against leaching down the anions, cations and the toxic compounds towards the ground water. However, many potential applications are still under development and still require more studies and research.

**The aim of this research:** The aim of this research is to study the effect of integration between temperature and time factors during the carbonization process on some properties of biochar prepared from peanut pods.

## 2. materials and methods:

### A. The raw material of the biomass:

The raw material of peanut pod residues (peels), was used in this study as a source for the biomass to prepare biochar. The peanut crop is a local type that is a summer crop which is usually grown at the coastal area of Syria.

### B. Experimental design and implementation:

The experiment included (12) treatments, consisting of (4) levels of carbonization heat (C) (350, 450, 550 and 650 °C) in combination with (3) levels of carbonization residence time (15, 30 and 60 minutes), and 3 replicates for each treatment as shown in Table (1):

**Table (1): shows number of samples and treatments codes**

Treatment number	1	2	3	4	5	6	7	8	9	10	11	12
Carbonization temp-C (°C)	C <sub>1</sub> = 350 °C			C <sub>2</sub> = 450 °C			C <sub>3</sub> = 550 °C			C <sub>4</sub> = 650 °C		
Residence time– T(minutes)	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
	15	30	60	15	30	60	15	30	60	15	30	60

The carbonization temperatures ranges, were chosen between (350 °C- 650 °C) because our primary study showed that at temperatures lower than (350 °C) all biomass carbon was not converted to biochar and the ratio of non-charred impurities remained high, while temperatures above (800 °C) caused decrease in the productivity of biochar, due to the decomposition of its particles and the fusion of the carbon structures that form the biochar, (Lua *et al.*, 2004). This experimental work was carried out in lab of soil fertility and plant nutrition - Soil and Water Science Department in Tishreen University, where homogeneous samples of peanut pods weighing (50 g) per sample, were placed in 100 cm<sup>3</sup> metal cylinders, covered with heat-resistant aluminum foil to prevent the entry of air, perforated to exit of combustion gases and water vapor, (Picture 1).



**Picture 1: peanut pods samples in metal cylinders intended for carbonization.**

The cylinders were placed in the furnace at stated temperatures with different carbonization periods according to the above-mentioned treatments. After the completion of the carbonization process the samples were taken out and placed to cool down. Then, the resulting weights of the residues, were recorded, and the loss of biomass was calculated for treatments and attributed to the original weight as a percentage of the biomass. After that, the carbonized samples were preserved in small plastic containers, well stoppered, marked with treatments numbers, temperature and time of charring, and kept for lab measurements and tests.

### **C. Measurements and tests:**

- **Biochar Purity (%):**

The degree of biochar purity and ash percentage were determined by burning biochar samples weighing ( $X_1 = 5$  g) each, in a porcelain crucible at a temperature of ( $500^\circ\text{C}$ ) for (5) hours, cooled down, and the resulting ashes which represent the mineral impurities were weighed ( $X_2$ ). Then the purity of the biochar and the percentage of ash in each sample were calculated as follows:

$$\% \text{ Biochar} = (X_1 - X_2) / X_1 \times 100$$

$$\% \text{ Ash} = 100 - \% \text{ biochar}$$

- **Organic Carbon (O.C)  $\text{g.kg}^{-1}$ :**

The presence of the organic carbon in the biochar was estimated by the color method according to (Motsara and Roy, 2008), after wet digestion with potassium dichromate method according to (Walkley and Black, 1934).

- **(pH):**

Water suspensions of biochar, type (pH1/10), were prepared for all treatments and their replicates. After waiting for (30 minutes), pH was measured and readings were recorded and prepared for the statistical analysis.

• **Cation and Anion Exchange Capacity (CEC &AEC) cmol.kg-1:**

The cation and anion exchange capacities of the biochar (CEC + AEC) were estimated by the modified method of barium chloride (BaCl<sub>2</sub>), (Mehlich. 1953), which depends on saturating the biochar samples with high concentrations, (1N), of barium cations and chloride anions, to replace all cations and anions adsorbed on the surfaces of the biochar particles, then calculate the (CEC and AEC) in cmol.kg-1, by estimating the ions of both (Ba<sup>++</sup>) and (Cl<sup>-</sup>) adsorbed on the surfaces in a unit weight of biochar.

• **Soluble salts, g.kg-1:**

Concentrations of soluble salts in biochar were calculated by measuring the electrical conductivity (EC1/10) of the water suspensions of biochar, for all treatments and their replicates, after waiting for (30 minutes), according to (Richards, 1954).

• **Equivalent Calcium Carbonate (ECC %):**

The presence of carbonate in all its forms (CaCO<sub>3</sub>, MgCO<sub>3</sub>, K<sub>2</sub>CO<sub>3</sub>, Na<sub>2</sub>CO<sub>3</sub>) in biochar, especially the soluble part of it, is responsible for its alkalinity and hence the high pH value of more than (9), in the (1/10) type of water suspension of biochar and distilled water, is one of the most important impurities in biochar along with some mineral oxides. Carbonates of all types were estimated by burning a sample of dry biochar in a porcelain crucible at a temperature level of (500 oC) for 5 hours and then cooled down, and the resulted ash was treated with a known and excess amount of hydrochloric acid (HCl 4N), heating on low temperature till the complete dissolution and then the ECC was measured by back titration by (NaOH 1N) in the presence of red methyl reagent until fading the red color, (Matar and Zidan, 1984).

**D. Statistical Analysis:**

The 36 variables of the results for the 12 treatments and 3 replicates, were subjected to analysis of variance (Two ways ANOVA). Also, the least significant difference (LSD), was calculated, at (5%) level of significance, for the mean values of the treatment variables and their interactions, using the statistical program Genstat 12thEdition (NULL Corporation, 2009).

**3. Results and discussion:**

Table (2) shows the significant levels of the (F. probability) of the variance analysis of the effects of the two factors of temperature (C), and carbonization timing (T), on the changes in the recorded values of some contents and properties of the produced biochar; (biochar%, impurities%, CCE %, soluble salts g.kg-1, pH, CEC, AEC and O.C %.). It shows a very high significant levels for the factors effects for all studied parameters. Similar results were mentioned by Imam and Capareda (2012), on specific surfaces and (Kwapinski, *et al.*, 2010), on biochar productivity%. And the highly significant effects of the combinations between the two factors, means that each carbonization temperature with different timings give different biochar properties.

As for Table (2), it shows the means recorded values of the biochar contents under the effect of different treatments of the heating temperatures and timings during the carbonization processes of the biomass.

**Table(2): Average changes of Biochar contents under the effect of the temperature (C) and the carbonization time (T) factors**

Charring Temp °C	Time of Charring (m)	Biochar Purity %	Impurities %	Equivalent CaCO <sub>3</sub> %	Soluble Salts g.kg <sup>-1</sup>
350 = =	15	54.20 e	45.80 a	3.93 i	6.45 k
	30	55.40 d	44.60b	4.55 g	6.78 i
	60	56.60 c	43.40 c	6.84 e	8.39 f
450 = =	15	57.00 c	43.00 c	4.35 h	6.54 j
	30	58.20 b	41.80 d	7.16 d	7.76 g
	60	79.00 a	21.00 e	7.99 c	9.42 c
550 = =	15	57.80 b	42.20 d	4.85 f	6.96 h
	30	79.20 a	20.80 ef	8.27 ab	9.30 e
	60	80.00 a	20.00 g	8.17 b	9.37 d
650 = =	15	80.00 a	20.00 g	8.36 a	9.58 b
	30	79.73 a	20.2 0 g	8.37 a	9.62 a
	60	79.60 a	20.40 gf	8.35 a	9.57 b
F.pr	-	***	***	***	***
LSD 0.05%	-	0.473	0.475	0.141	0.025

Similar letters in the same column mean no significance

### A- Physical Parameters

#### • Biochar purity and impurity %

Table (2) shows the mean values of the loss and left over values of the biomass after carbonization under the effects of four levels of carbonization temperature (C) during three timing periods (T), as well as the degree of purity of the biochar in the carbonized products. Where the table clearly shows that, there is a highly significant levels (<0.001) for the effects of the two factors (C and T) on the biochar productivity (%), of the biomass after carbonization, where it is decreased with increasing temperature from (350 °C up to 650 °C) through (450 °C and 550 °C), And by increasing the charring period from ¼ to ½ and then to 1 hour, the carbonization process begins to end and get stabilized when the temperature reaches at (450 °C) for one hour or (550 °C) for ½an hour or (650 °C) for ¼an hour or longer.

The carbonization process did not reach the stability stage at charring temperature of (350 oC) when the carbonization period was less than an hour, or (450 oC) when it was less than ½ an hour. These results were consistent with the results of many researchers, (Ahmed, *et al.* 2007; Asadullah, *et al.* 2011), where they observed a decrease in the bulk of the biomass and the percentage of impurities of the produced biochar with increasing carbonization temperature from (350 to 650 oC). The decrease in the impurity from (45.8%) to about (20%), was related to the volatilization of gases and water vapor during the carbonization process with the increase in the temperature and period of charring, as the combustion process stops and most of the organic carbon is converted to elemental carbon (graphite). Where the biochar purity increases from (54.2 %) at temperature of (350 oC) to (79 %) at temperature of (450 oC) for an hour to about (80 %) at temperature of (550 oC) for a period of ½ an hour or (650 oC) For ¼ an hour. Similar results were found by (Keilluweit, *et al.* 2010), in terms of increasing the elemental carbon and decreasing the organic carbon in the produced biochar as the carbonization process advanced.

As the low percentage of biochar and the high percentage of impurities in the charred product, indicates a low efficiency and incomplete carbonization process, getting stability in the value of the biochar percentage at its highest level (79.2--80%) with an impurity percentage at its minimum level (20-21%), means high efficiency of the carbonization process

- **Equivalent Calcium Carbonates % (ECC):**

The percentage of the equivalent calcium carbonates (ECC) in the formed biochar, increased with increasing temperature and duration of charring of the biomass, as a result of the conversion of most minerals to carbonates during charring process, and there was a semi-stability of its values between (8.35 - 8.37%) at a temperature of (650 oC) with the three timings ¼, ½, and 1 hour, with no significant differences observed with charring temperature of (550 oC) for more than ½ an hour or (450 oC) for more than 1 hour, (Table 2). This finding was consistent with the results of Cao and Harris (2010), as they confirmed that the minerals and carbonates of minerals were concentrated gradually in the biochar with the progress of the carbonization process.

- **Soluble salts (g.kg<sup>-1</sup>):**

As shown in table (2), the biochar contents of soluble salts, increased with the progress of carbonization process, as the soluble salts recorded a rate of (6.45 g.kg<sup>-1</sup>) with the temperature (350 oC) at carbonization time of ¼ an hours and increased slightly to (6.78 g.kg<sup>-1</sup>) at ½ an hour and then jumped to (8.39 g.kg<sup>-1</sup>) at 1 hour. The highest value (9.62 g.kg<sup>-1</sup>), was recorded at (650 oC), and was nearly stable at this value since there were no significant differences between the effect of the three timings. These results were reliable with the results of (Joseph *et al.* 2007) and (Cantrell, *et al.* 2012), These were explained by the loss of the volatile substances and the increase in the ratio of the mineral elements in the ash mass, as a part of these mineral contents in the ash is soluble, and therefore, gives a remarkable electrical conductivity for the biochar suspension, especially potassium and sodium carbonates.

## **B- Chemical Properties**

The mean values of laboratory measurements for some chemical properties of biochar and their changes under the effect of temperature (C) and timing (T) of biomass carbonization of peanut pods,



are shown in table (3), where it looks very clear that, there is very strong effect for the studied factors on the measured properties.

**Table (3): The mean values of some Biochar properties under the effect of the temperature (C) and the carbonization time (T) factors**

Charring Temp °C	Time of Charring (m)	pH <sub>1/10</sub>	CEC cmol.kg <sup>-1</sup>	AEC cmol.kg <sup>-1</sup>	O.C g.kg <sup>-1</sup>
350	15	7.77 g	113.48 ed	19.48 e	20.83 a
	30	7.84 f	120.77 d	22.43 d	19.65 b
	60	8.58 e	131.94 c	27.78 c	18.53 c
450	15	7.86 f	118.80 d	21.52 d	19.89b
	30	8.87 d	135.09 c	26.32 c	16.38 e
	60	9.32 b	160.12 b	34.57 b	15.46 f
550	15	8.59 e	127.53cd	28.30 c	18.26 d
	30	9.32 b	161.17 b	35.71 b	14.86 g
	60	9.29 c	158.30 b	34.57 b	14.26 h
650	15	9.44 a	168.87 a	36.71 a	13.80 i
	30	9.42 a	172.54 a	37.63 a	13.38 j
	60	9.43 a	172.16 a	38.46 a	13.28 j
F.pr	-	***	***	***	***
LSD 0.05%	-	0.02	5.935	2.561	0.254

Similar letters in the same column mean no significance

- **Biochar Reaction, (pH<sub>1/10</sub>):**

The pH values of the 1/10 suspension type of the produced biochar, increased with increasing the temperature and time of carbonization of the biomass and reached to a semi-stable values at two temperatures, (550 and 650 °C), during the three timings of charring, and at (450 °C) for only an hour. This corresponds with the mentioning of Tsai and colleagues (2012), as they explained that the minerals begin to separate from the organic complexes when ash is formed at temperatures in excess of (350 °C). Keiluweit and colleagues (2010), referred this increase in pH values, to the high contents of alkali minerals carbonates in its ash, and the loss of the low-acid functional groups such as phenols and carboxylates when the temperature rises during carbonization processes

- **Cation Exchange Capacity (CEC), cmol.kg<sup>-1</sup>:**

The biochar (CEC), increased with increasing temperature and time of carbonization, where its values stabilized at temperature (650 oC) and recorded (168.87 - 172.52 cmol.kg-1), when the time of

carbonization, exceeded a  $\frac{1}{4}$  an hour. This is consistent with the findings of Lehmann, (2007), and approve the results of many other researchers such as (Yuan, *et al.*, 2011; Zhao, *et al.*, 2017), who indicated that the increase in the carbonization temperature causes an increase in the specific surface area of the biochar particles. Similarly, Angin, (2012) found that, carbonization of the biomass at (650 °C) increased the surface area of the resulting biochar particles by (70%).

- **Anion Exchange Capacity (AEC)  $\text{cmol.kg}^{-1}$ :**

The biochar (AEC), was affected in similar way as the (CEC), by the temperature (C) and time of carbonization (T) factors, where its value increased with increasing (C) and (T) from about (28  $\text{cmol.kg}^{-1}$ ) at temperature value of (350 °C) to about (39  $\text{cmol.kg}^{-1}$ ) at temperature of (650 °C), this consistent with the results of Lawrinenko, (2014), which indicated that the biochar produced from alfalfa, corn and cellulose at carbonization temperatures (500 and 700 °C) contains relatively high levels of (AEC), when the carbonization is done at higher temperatures. Also, this result is supported by the findings of Lawrinenko and Laird (2015), which explained this increase in (AEC), by the intense formation of aromatic rings in the crystalline structure of carbon molecules, which contribute in increasing the positive sites on the surfaces of the biochar particles.

- **Organic carbon (O.C  $\text{g.kg}^{-1}$ ):**

The presence of organic carbon in the carbonized products were tested as an evidence of the incomplete carbonization process, as the percentage of the stuck (O.C) in the carbonized products recorded the highest value (20.83 $\text{g.kg}^{-1}$ ), at the lowest tested temperature of (350 °C), and recorded the lowest value (13.3 $\text{g.kg}^{-1}$ ) at the highest temperature of (650 °C). It seems that there is a clear inverse relationship between the (O.C) stuck in the biochar and both factors of temperature and carbonization timings. These results were consistent with the findings of: (Keilluweit, *et al.* 2010; Gai, *et al.* 2014; and Zhao, *et al.* 2017), where they show a decrease in the biochar content of (O.C) and an increase in the percentage of mineral carbon, (elemental carbon), with increasing the temperature of carbonization, as shown in Table (3).

#### 4. Conclusions:

The results confirm that there is a clear integration effect between the temperature and the period of carbonization of biomass on the studied physical and chemical properties of biochar, as the percentage of impurities decreased and the purity of the resulting biochar increased with the increase in the temperature and period of carbonization, as the purity in the carbonization products recorded a value of (54.2%) at (350 °C) and increased to (79%) at (450 °C) for a period of an hour, and to 80% at a temperature of (550 °C) for a period of  $\frac{1}{2}$  an hour, or (650 °C) for a period of  $\frac{1}{4}$  an hour. Also, the content of the equivalent carbonates and the amount of soluble salts in the resulting biochar recorded the highest values at temperature (650 °C) under the influence of any carbonization period greater than  $\frac{1}{4}$ an hour.

The biochar reaction (pH), the cation exchange capacity (CEC) and the anion exchange capacity (AEC), were affected similarly to carbonate and dissolved salts in biochar under the effect of temperature and the period of carbonization, where high values were recorded at temperatures (450 °C) for an hour, (550 °C) for more than  $\frac{1}{2}$ an hour and (650 °C) for more than  $\frac{1}{4}$ an hour. Finally, the

clear inverse relationship between the (O.C %) stuck in the biochar and both factors of temperature and carbonization period should be an indicator to the degree of the far-reaching carbonization process.

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