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Research Article

Effects of Different Carbonization Conditions on the Color Change of Biochar

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ABSTRACT

The aim of this research was to determine the effects of different carbonization temperature, gas flow rate and heating rates on biochar's color change. Three different carbonization temperatures (400°C, 500°C, and 600°C), two different gas flow rates (0.2 l min^{-1} and 0.5 l min^{-1}) and two different heating temperature rates (30°C min^{-1} and 60°C min^{-1}) were used in the experiments. The color changes of biochar were examined utilizing the international approved *L*, a*, b** system. Atriplex nitens Schkuhr was used as a biomass source in the experiments. High carbonization temperature and high gas flow rate caused a decrease in the "*L*" value of biochar. It is an indication that the color is getting darker, when the *L* value approaches zero. In the study, only the effect of gas flow rate on the "*a*" value was found to be statistically significant (P≤0.05). The increase in gas flow rate caused the biochar to become darker by increasing the deep red tone. Heating rate and gas flow speed significantly influenced the "*b*" values of biochar. The slow heating rate and high gas flow rates made the biochar color darker. At end of the research, it can be said that the biochar produced at high carbonization temperature, low heating rate and high gas flow rates will have darker tones.

RESEARCH ARTICLE

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- *Atriplex nitens Schkuhr*,
- Pyrolysis,
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- Biomass

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INTRODUCTION

Biochar is a high carbon content combustion product formed by the combustion of organic material by thermochemical transformation processes in oxygen-free or limited oxygen conditions (Hardie *et al.*, 2014). Biochar contains between 60% and 80% C, depending on the production properties (Castellini and Ventrella, 2015). Due to this feature, it can be applied as a soil amendatory at the agricultural soils which have low carbon content (Genesio *et al.*, 2015). At the several studies have examined the effects of biochar on agricultural soils. According to the obtained results; biochar increases soil carbon content (Lal, 2015) and crop yield (Brassard *et al.*, 2016), reduces CO_2 emission from soil to atmosphere. In addition, the biochar improves soil physical bulk density, porosity, infiltration rate and water holding capacity, chemical pH, electrical conductivity, cation exchange capacity, organic matter content and biological (microbial mass, microbial mass, enzyme activity quality criteria (Ding *et al.*, 2016; Brassard *et al.*, 2016; Mukherjee and Lal, 2017; Lehmann *et al.*, 2011).

The thermal properties of the soil were affected by soil bulk density, (Abu-Hamdeh and Reeder, 2000; Usowicz *et al.*, 2013) soil moisture content, (Usowicz *et al.*, 2006) organic matter level, (Dec *et al.*, 2009) and application method into the soil (Paz-Ferreiro *et al.*, 2014). Addition of biochar into the soil changes soil temperature (Logsdon *et al.*, 2010; *Genesio et al.*, 2012; Meyer *et al.*, 2012). The dark color of biochar darkens the soil color and changes the albedo of the soil surface. Albedo is the ratio of solar radiation reflected from the soil to the atmosphere. Dark colored soils absorb more sunlight and have lower surface reflection than other soils.

Biochar added soils have lower reflectance than other soils. This situation reduces evaporation and increases soil moisture content. The studies (Zhang *et al.*, 2013; *Usowicz et al.*, 2016) have shown that when biochar was added into the soil at the rate of 4.5 to 30 Mg ha^{-1}, the albedo rate decreases. The effect of biochar application on soil temperature differs in daytime and nighttime measurements. From this point of view, it can be said that biochar application is an alternative method that can prevent fluctuations in soil temperature. In some studies, it has been concluded that the application of biochar into the soil increases soil temperature at night and reduces it during the day (Zhang *et al.*, 2013; Usowicz *et al.*, 2016; Ventura *et al.*, 2012). Oguntunde *et al.* (2008), stated that biochar application into the soil reduced soil albedo by 8%. In another study, when biochar at 30-60 t ha^{-1} norm was mixed into the soil, the albedo decreased more than 80% (Genesio *et al.*, 2012). In another study conducted in Germany, a 12% reduction in soil albedo was observed when the mixing biochar into the soil. (Meyer *et al.*, 2012).

The aim of this research is to determine how the carbonization temperature, heating rate and gas flow speed parameters used in the carbonization process cause a change in the color of biochar. In this research, biochar was produced in a laboratory type carbonization reactor at 3 different carbonization temperatures, 2 different heating rates and 2 different gas flow speeds.

MATERIALS and METHODS

Atriplex nitens S. plant was used as biomass material in the study (Figure 1a). After the plant was harvested, it was extracted from its branches, and the trunk part was ground in a laboratory type mill (Figure 1b) so that the aggregate diameter was less than 2 mm. The ground biomass was dried in the oven at 105°C for 24 hours (Suthar *et al.*, 2018).

A fixed bed laboratory type carbonization reactor (Figure 2) was used for the carbonization experiments. In the experiments three carbonization levels, two heating rates and two gas flow rates were used for biochar production. The experimental factors and levels were given in the Table 1.

a b

Figure 1. *Atriplex nitens Schkuhr* (a) and laboratory type mill (b).

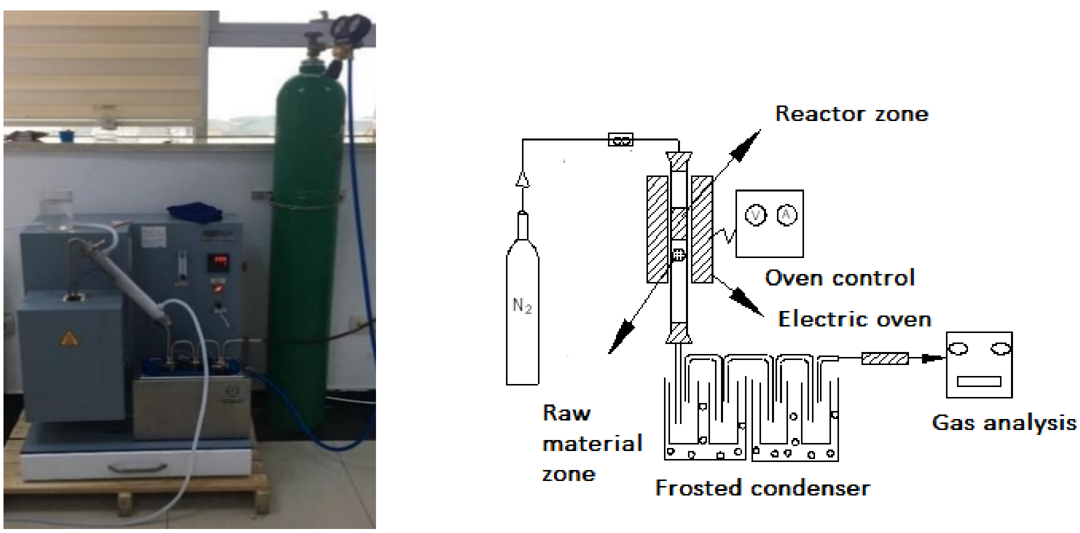

Figure 2. Fixed bed carbonization reactor and its schematic view.

Figure 3. Biochar obtained from the experiments.

Table 1. Experimental factors and factor levels.

Experimental factors	Factor levels
Carbonization temperature (°C)	400, 500, 600
Heating rate (°C min^{-1})	30, 60
Gas flow speed (l min^{-1})	0.2, 0.5

Before starting the experiments, the ground and oven dried biomass sample weighing 10 grams was placed in the carbonization reactor. Before the carbonization process, nitrogen gas was supplied to the system to eliminate the existing oxygen. In order to determine the color changes of biochar, color measurements were made after the carbonization process. Color measurement was carried out the international *L*, a*, b** system in the study (Figure 4). The "*L*" value represents brightness and ranges from 0 to 100 values. In the *L* value, zero (0) means blackness and hundred (100) means whiteness. In addition, "*a*" and "*b*" value is an indicator of redness - greenness, and blueness - yellowness, respectively. The "*a*" and "*b*" values vary between -90 - +90. A color measurement device (PCE-CSM 4) was used to determine the "*L*", "*a*" and "*b*" values (Figure 5).

The data received from each experiment with three replications were analyzed statistically to test for differences among treatments. An ANOVA procedure was used to perform the analysis of variance. Means were separated by Duncan when treatment effects were significant. IBM SPSS Statistic 25 program was used for statistical analyses.

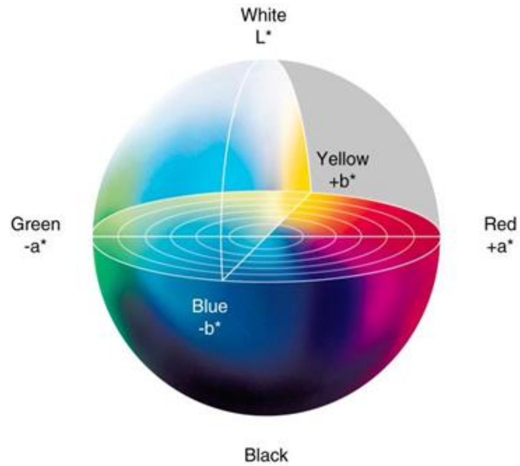

Figure 4. CIE *L*, a*, b** color space.

Figure 5. Color measurement device used in the experiments.

RESULTS and DISCUSSION

Variance analysis of the results regarding the *L* value of biochar produced under different conditions was given in Table 2. According to the results of the variance analysis, it can be said that the carbonization temperature and gas flow speed have statistically significant effects on the *L* parameter.

Table 2. Variance analysis results of *L* change in the biochar color.

Factors	*L*	
	F	**P**
Carbonization temperature (C.T)	19.72	0.000**
Heating rate (H.R)	2.99	0.097ns
Gas flow speed (G.S)	18.14	0.000**
C.T.* H.R	6.07	0.007**
C.T. * G.S	3.28	0.055ns
H.R. * G.S	0.054	0.818ns
C.T.* H.R. *G.S	2.2	0.133ns
Mean square error	46.004	

C.T: Carbonization temperature; H.R: Heating rate; G.S.: Gas flow speed; **: Statistically highly significant (P <0.01); *: Statistically significant (P <0.05), ns: Statistically non-significant

In the study, due to the increase in carbonization temperature, *a* decrease in the *L* value occurred. The lowest "*L*" value was obtained at a carbonization temperature of 600°C with 19.26 value. In addition, at the 400°C temperature "*L*" values were determined as 36.04. As a result of the experiments, an inverse relationship was determined between gas flow speed and the "*L*" value. It was observed that the "*L*" value decreased due to the increase in gas flow speed (Figure 6).

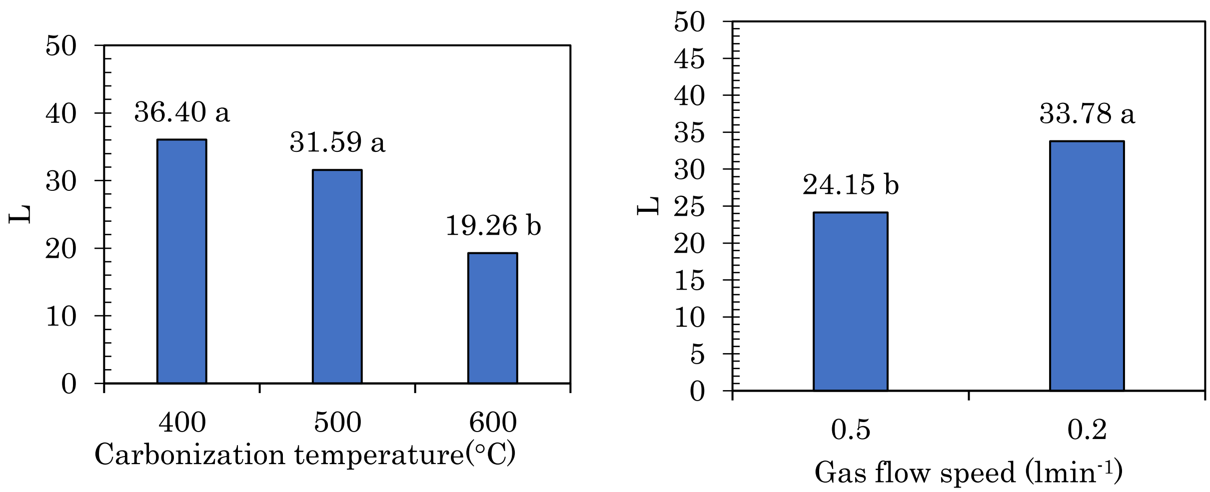

Figure 6. The change of "*L*" value according to carbonization temperature and gas flow speed.

The "*L*" value is considered a measure of black and whiteness. It means that the color gets darker as the "*L*" value approaches 0, and becomes white as it approaches 100. According to the results, it was concluded that the biochar produced at 600°C carbonization temperature and 0.5 l min^{-1} gas flow speed was darker color. The increase in gas flow speed caused an oxygen-free environment in the system at the time of carbonization, thus the raw material was completely carbonized without burning and turned darker.

Variance analysis results regarding the "*a*" value of biochar in the study are given in Table 3. According to the results, among the main factors, only the effect of gas flow speed on the "a" value was found to be statistically significant (P ≤0.05). The "*a*" values of biochar were determined as -8.76 and -1.67 for 0.2 and 0.5 l min^{-1} gas flow speed, respectively (Figure 7).

The "*a*" value denotes the red and greenness of the material color and takes a value between -90 and +90. Negative and positive values refer to red and green shades, respectively. As an expected result, the green shade of biochar was not observed.

Table 3. Variance analysis results of "*a*" change in the biochar color.

Factors	*a*	
	F	P
Carbonization temperature (C.T)	2.011	0.156ns
Heating rate (H.R)	1.280	0.269ns
Gas flow speed (G.S.)	6.096	0.021*
C.T.* H.R	7.478	0.003**
C.T. * G.S.	4.026	0.031*
H.R. * G.S.	0.034	0.856ns
C.T.* H.R. *G.S.	2.466	0.106ns
Mean square error	74,290	

C.T: Carbonization temperature; H.R: Heating rate; G.S.: Gas flow speed; **: Statistically highly significant (P<0.01); *: Statistically significant (P<0.05), ns: Statistically non-significant

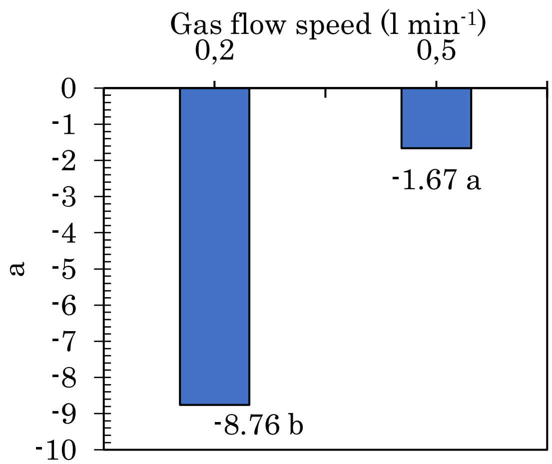

Figure 7. The change of "*a*" value according to gas flow speed.

The "*b*" value in the material color denotes tones of blue and yellow. The value of "*b*" takes a value between (-90) and +90. Negative and positive values refer to blue and yellow color tone, respectively.

Variance analysis results of the *b* value of biochar were given in Table 4. As a result of the variance analysis, it is seen that among the main factors, the heating rate and gas flow speed were statistically highly important (P ≤0.01) and important and (P ≤0.05), respectively.

Table 4. Variance analysis results of "b" change in the biochar color.

Factors	*b*	
	F	**P**
	1.80	0.187ns
Carbonization temperature (C.T)	12.90	0.001**
Heating rate (H.R)	4.88	0.037*
Gas flow speed (G.S)	9.35	0.001**
C.T.* H.R	1.99	0.158ns
C.T. * G.S.	0.13	0.712ns
H.R. * G.S.	3.08	0.064ns
C.T.* H.R. *G.S.	306.276	

C.T: Carbonization temperature; H.R: Heating rate; G.S.: Gas flow speed; **: Statistically highly significant ($P<0.01$); *: Statistically significant ($P<0.05$), ns: Statistically non-significant

The "*b*" values of biochar were determined to be negative. This result means that the biochar does not have a yellow tone and contains a tone close to navy blue. In the study, "*b*" values at 30°C min^{-1} and 60°C min^{-1} heating rates were determined as -43.63 and -22.68, respectively (Figure 8). Based on this result, it can be said that the color of biochar obtained at slow heating rates has a dark blue tone. In the study, the increase in gas flow rate caused the blue tone of biochar to darken. As a result of the experiments, the *b* value was determined as -26.71 at 0.5 l min^{-1} gas flow rate. Figure 8 illustrated that the change of *"b"* value according to heating rate and gas flow speed.

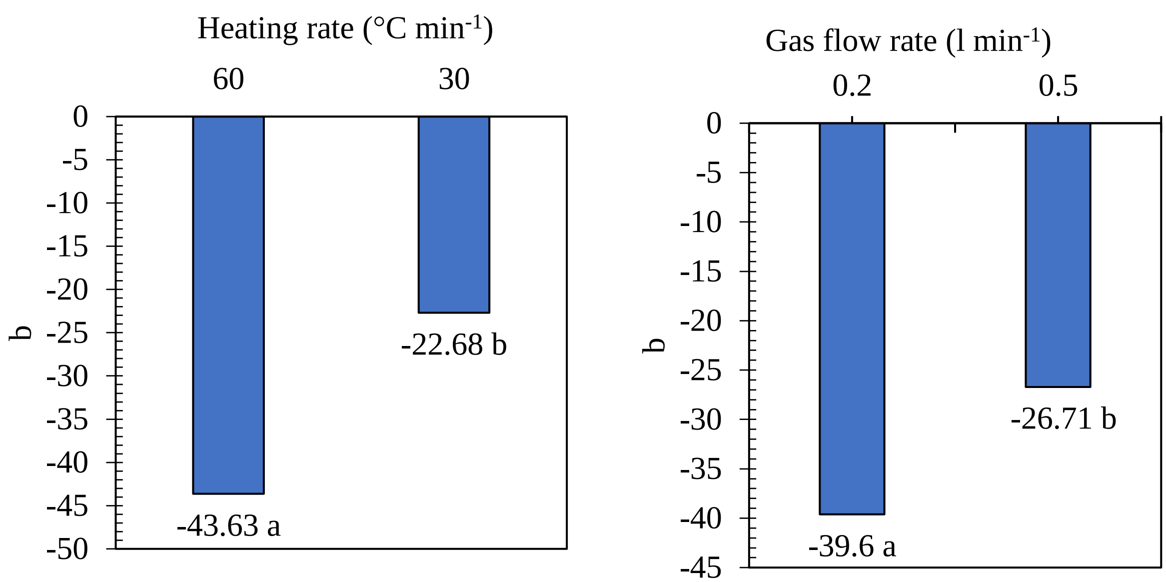

Figure 8. The change of "*b*" value according to heating rate and gas flow speed.

CONCLUSION

Due to its high carbon content and porous structure, biochar improves soil quality if mixed in to the soil with suitable methods. The biochar added soils have darker tones compared to other soils. This property of biochar affects soil albedo. The soils which were mixed with biochar have more darkness color compare to other soils. Therefore, this type of soil absorbs more sunlight than other soils thus the soil temperature rises. This effect changes accordance with day and night measurements.

In this study, the effects of different carbonization temperatures, gas flow rates and heating rates used in biochar production on changes in the color of biochar were investigated. As the carbonization temperature increased, the "*L*" value of biochar decreased. The fact that the *L* value approaches zero is an indication that black tones are more dominant. According to these results, high carbonization temperature leads to the formation of darker colored biochar. However, the issue to be considered here is the selection of gas flow rate and heating rates that are compatible with high carbonization temperature. If the carbonization temperature rises, an oxygen-free environment must be obtained in the system. In order to achieve such an environment, it may be suggested to increase the gas flow rate and decrease the heating rate. A similar trend was determined between gas flow rate and "*L*" values. In the study, due to the increase in the gas flow rate, a decrease in the "*L*" value occurred and darker biochar was obtained.

In the study, only the effect of gas flow rate on the "*a*" value was found to be statistically significant. The increase in gas flow rate caused the biochar to become darker by increasing the deep red tone. Heating rate and gas flow speed significantly influenced the "*b*" values of biochar. According to "*b*" values at the slow heating rate and high gas flow rates made the biochar color darker. Based on these data it can be said that the biochar produced at high carbonization temperature, low heating rate and high gas flow rates will have darker shades.

DECLARATION OF COMPETING INTEREST

The authors hereby declare that they have no conflict of interest whatsoever.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors hereby declare that the contributions given are correct.
Alperay Altıkat: Laboratory experiments, statistical analysis, writing the manuscript.
Mehmet Hakkı Alma: Examination, editing and formal analysis of manuscript.

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