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Research Article

Relationship between Color $\mathrm{CIE}_{L^*a^*b^*}$ and Total Organic Carbon in Compost

Jhon Jairo Palechor-Tróchez,[1,2] Luis Eduardo Ordoñez Santos,[2] and Hector Samuel Villada-Castillo[1]

[1]*Faculty of Agrarian Sciences, Department of Agribusiness, University of Cauca, Calle 5 N 4-70, Popayán, Cauca, Colombia*
[2]*Faculty of Engineering and Administration, Department of Engineering, National University of Colombia-Palmira Headquarters, Carrera 32 N 12-00, Palmira, Valle del Cauca, Colombia*

Correspondence should be addressed to Jhon Jairo Palechor-Tróchez; jjpalechor@unicauca.edu.co

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The $\mathrm{CIE}_{L^*a^*b^*}$ coordinates and the total organic carbon content in compost were correlated. Two particle sizes of 0.5 and 2 mm were obtained in the compost samples; the surface color was analyzed with a $\mathrm{CIE}_{L^*a^*b^*}$ colorimeter and the total organic carbon content by spectrophotometry at 588.9 nm. The results indicate that all chromaticity values were significantly affected ($p < 0.001$) by particle size. Chromaticity values a^*, b^*, C^*, and h° showed significantly strong Pearson correlations ($r > 0.95$). The coordinates a* ($r = -\mathbf{0.992}$) and b^* ($r = \mathbf{0.968}$) have the potential to be used in estimating the total organic carbon concentration in the compost samples analyzed.

1. Introduction

Nowadays, large amounts of solid and liquid waste are produced in the processing of fruits and vegetables on the planet, accounting for about 93% of the waste generated by food processing, mainly fruits and vegetables, and it is very common that this type of waste end up in landfills [1]. Composting of organic residues such as those derived from the processing of fruits and vegetables is considered one of the most relevant options for its treatment, from an economic and environmental point of view, since compost can be used as fertilizer [2, 3].

Composting is considered a process of biological decomposition of organic materials under controlled conditions, these conditions must guarantee an aerobic environment, and the product derived from this process is called compost [4, 5]. Composting combines the activity of a wide variety of microbial population and various physical and chemical factors that are affected by different environmental conditions of humidity, temperature, and among others that influence the composting process [6, 7].

In order to establish the parameters of the quality and to evaluate the compost, it is necessary to look for methodologies that allow to evaluate the content and the stability of the organic matter, mainly the total organic carbon content (TOC), and in this way to be able to determine the advantages and the possible uses of elaborated compost [8–10]. There are several procedures used to determine TOC or organic matter, including volumetry and spectrophotometry, where the organic matter is treated with an optimum volume of a solution of potassium dichromate, which acts as an oxidizing agent in the acid medium, assessing by retrogression the amount of dichromate that has not reacted with the organic matter by titration with a ferrous sulphate solution or by measuring the absorbance at 585 nm, respectively [11]. Equation (1) explains the reaction of the process and has been previously described by Garcia Galvis and Ballesteros González [11] and Jha et al. [12].

Table 1: Means obtained in the estimate of the TOC.

Number	Sample	TOC (mg/g)
1	0.5 mm_1	99.13
2	0.5 mm_2	92.45
3	0.5 mm_3	77.77
4	1 mm_1	100.16
5	1 mm_2	77.13
6	1 mm_3	103.49
7	2 mm_1	84.76
8	2 mm_2	80.38
9	2 mm_3	100.47

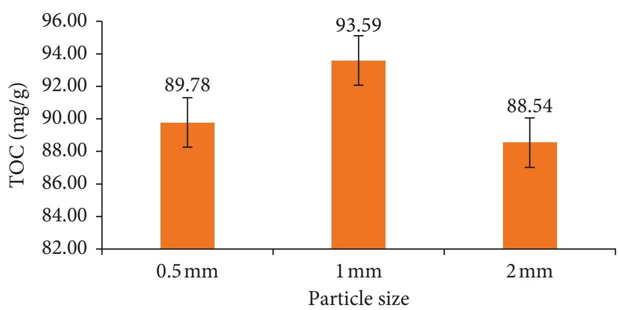

Figure 1: Mean content of TOC.

$$6C_6H_{12}O_6 + 4K_2Cr_2O_7 + 16H_2SO_4 \longrightarrow 4K_2SO_4 + 4Cr_2(SO_4) + 3CO_2 + 22H_2O \quad (1)$$

Another technique, quite useful, practical, and fast, is the use of a TOC analyzer, however, it is a highly expensive method [1], in this sense, nowadays, one of the alternatives is the use of colorimetric techniques, among which are highlighted the determination of the $\mathrm{CIE}_{L^*a^*b^*}$ coordinates, and Khan et al. [13] commented that organic matter is one of the components that is directly related to the color variables $\mathrm{CIE}_{L^*a^*b^*}$.

Research papers are currently required to correlate the $\mathrm{CIE}_{L^*a^*b^*}$ color parameters with the TOC, as it is information of great interest in the construction of fast and inexpensive methods that could be very useful in the evaluation of quality in compost production and storage processes. It is because of the above that the objective of the present work was to correlate the $\mathrm{CIE}_{L^*a^*b^*}$ coordinates and the total organic carbon content in compost.

2. Materials and Methods

2.1. Materials. The compost samples were collected in the compost place located at "La Rejoya" farm of Universidad del Cauca, Colombia, made from the organic residues generated in all university faculties, with approximately 90 days of maturation, and it was immediately transferred to the Laboratory of Rheology and Packaging of the Universidad del Cauca, where it was dried in a forced convection oven of Memmert brand of 40 L at 105°C for approximately two hours, until a final humidity of 1.39% was measured in a balance of humidity Precisa XM50.

Table 2: TOC and $\mathrm{CIE}_{L^*a^*b^*}$ values in compost samples in two particle sizes.

Size	TOC (mg/g)	L^*	a^*	b^*	C^*	$h°$
A	77.15	30.71	2.87	4.33	5.19	56.42
A	77.77	30.96	2.86	4.32	5.18	56.48
A	78.39	30.97	2.88	4.33	5.20	56.39
A	92.03	30.97	2.73	5.14	5.82	62.02
A	92.03	31.12	2.71	5.14	5.81	62.19
A	93.27	31.12	2.70	5.15	5.81	62.31
A	98.93	31.13	2.67	5.04	5.70	62.07
A	98.93	31.27	2.66	5.05	5.71	62.26
A	99.55	31.27	2.64	5.05	5.70	62.36
B	84.56	30.13	2.82	3.78	4.71	53.30
B	84.56	29.62	2.73	3.54	4.47	52.41
B	85.18	29.62	2.76	3.53	4.48	51.97
B	80.38	30.38	2.72	3.53	4.61	53.95
B	80.38	29.89	2.77	3.59	4.54	52.38
B	80.38	30.13	2.75	3.72	4.62	53.55
B	100.47	30.51	2.51	4.85	5.46	62.60
B	100.47	30.50	2.54	4.82	5.45	62.23
B	100.47	30.50	2.53	4.83	5.46	62.34
A	89.78 ± 10.92^a	31.12 ± 0.15^a	2.75 ± 0.11^a	4.84 ± 0.44^a	5.57 ± 0.33^a	60.28 ± 3.31^a
B	88.54 ± 10.56^a	30.14 ± 0.35^b	2.68 ± 0.13^b	4.02 ± 0.70^b	4.86 ± 0.51^b	56.08 ± 5.48^b
T-Student	NS	***	***	***	***	***

A = compost with a particle size of 0.5 mm; B = compost with a particle size of 2 mm; $\alpha = 0.05$.

The dry samples were ground in a Kinematica PX-MFC 90 D analytical mill, successively grinding at 3,000 rpm using the 2 mm sieve; once the compost was ground, the amount of sufficient sample was taken and the remaining sample was ground with the a 0.5 mm sieve. The samples were stored in a desiccator at an average room temperature of 15 to 19°C for analysis.

2.2. Determination of TOC by Spectrophotometry. The extraction and quantification of the carbon in the compost was worked based on the method proposed by Garcia Galvis and Ballesteros Gonzales [11]. 0.5 g of compost was weighed, which was previously desiccated at 105°C for two hours; the sample was taken in a 100 mL beaker, and with a 10 mL graduated pipette was added 5 mL of potassium dichromate solution (0.17 N), stirred gently to homogenize, and then with a 10 mL graduated pipette 10 mL of concentrated sulfuric acid was added, stirred gently, and allowed to stand for about 30 minutes. After 30 minutes, 50 mL of distilled water was added, mixed, and allowed to stand for about 14 hours. After 14 hours, the supernatant from the solution was transferred to tubes for 50 mL centrifuge and centrifuged in a Hermle Z306 centrifuge for 5 minutes at 3000 rpm. Finally, a 5 mL dilution of the supernatant solution in 10 mL of distilled water was performed, and the sample absorbance was measured at the wavelength 588.9 nm in a SHIMADZU UV-1800 spectrophotometer, being the maximum absorbance obtained during a preliminary scan between 550 nm and 650 nm for verifying

Table 3: Pearson correlation between TOC and the $CIE_{L^*a^*b^*}$ coordinates.

Size	L^*	a^*	b^*	C^*	h°	Regression equation	R^2	Error
A	0.852**	**−0.992*****	0.912**	0.887**	0.954**	COT = −97.533 (a^*) + 357.67	0.985	1.243
B	0.640^{NS}	−0.932**	**0.968****	0.956**	0.955**	COT = 14.39 (b^*) + 30.678	0.940	2.465
A	**0.852****	−0.992***	0.912**	0.887**	0.954**	COT = 45.797 (a^*) − 1332.60	0.727	5.297

A = compost with a particle size of 0.5 mm; B = compost with a particle size of 2 mm.

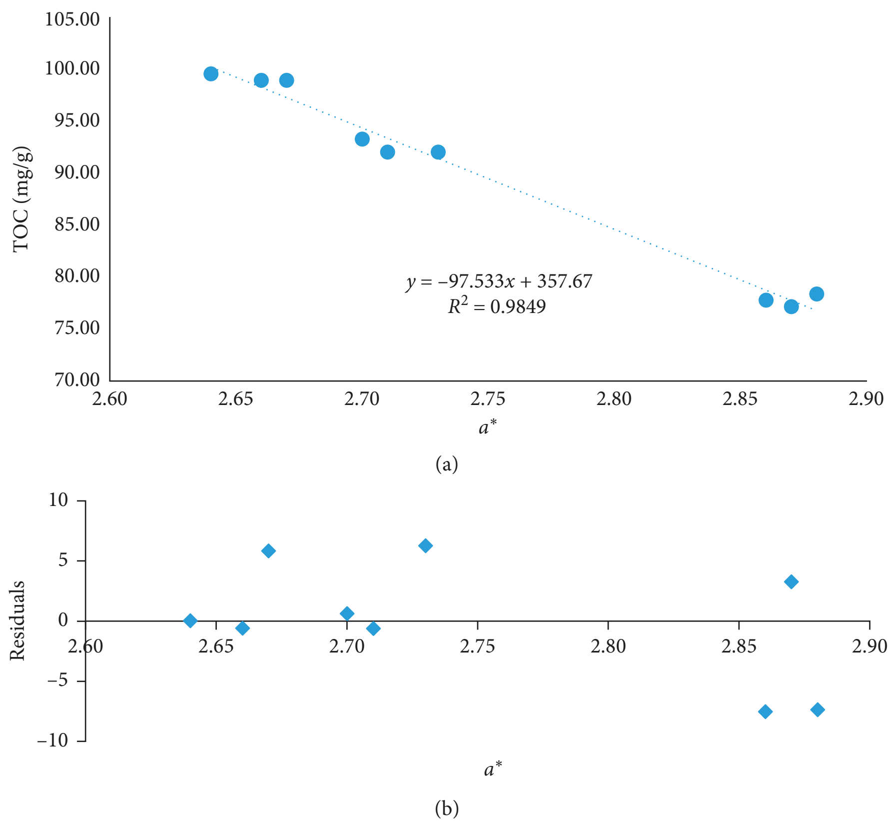

Figure 2: (a) TOC correlation versus a^* coordinate for compost at a particle size of 0.5 mm and (b) residuals plot.

the absorption spectra of chromic acid. The quantification of TOC (mg/g) was done through the calibration curve of a glucose pattern with a range of 0.81 to 10.99 mg/g for the elaboration of the line, with an R^2 of 0.9982 and (1), adapted from Dias et al. [14]:

$$\mathrm{TOC}\,(\mathrm{mg/g}) = \frac{\mathrm{Abs}_{588.9} - 0.0199 \times \mathrm{FD}}{0.0641 \times W_{\mathrm{sample}}}, \tag{2}$$

where TOC (mg/g) is the total carbon content, $\mathrm{Abs}_{588.9}$ is the sample absorbance, FD is the dilution factor, W_{sample} is the sample weight, and 0.0199 and 0.0641 are the factors of linear regression to the total carbon content.

2.3. Determination of $CIE_{L^*a^*b^*}$ Coordinates for Compost. This procedure was carried out in the laboratory of fruits and vegetables of Universidad Nacional de Colombia, located in Palmira. Color determination was done according to the methodology established by Khan et al. [13], using a Konica Minolta colorimeter model CR-A50, with an iluminant D65, with an observer angle of 2° for reference and with a calibration standard Y (89.5), X (0.3176), and Z (0.3347).

The powder samples with a particle size of 0.5 and 2 mm were measured using the CR-A50 for a granular material over a black background in three shots of light for each particle size, in triplicates. The color scale to be used was $CIE_{L^*a^*b^*}$, where L^* is the brightness indicator, a^* is the green (−) and red (+) chromaticity, and b^* the blue (−) and yellow (+) chromaticity. Chroma (C^*) and tone (h°) were estimated taking into account the equations of Saricoban and Yilmaz [15]:

$$\begin{aligned} C^* &= \sqrt{a^{*2} + b^{*2}}, \\ h^{\circ} &= \tan^{-1}\left(b^*/a^*\right). \end{aligned} \tag{3}$$

2.4. Statistic Analysis. A comparison of means of two treatments (0.5 mm and 2 mm) was performed; each treatment consisted of nine repetitions, and the difference between treatments was assessed with Student's T-test for independent samples, with a confidence interval of 95% in

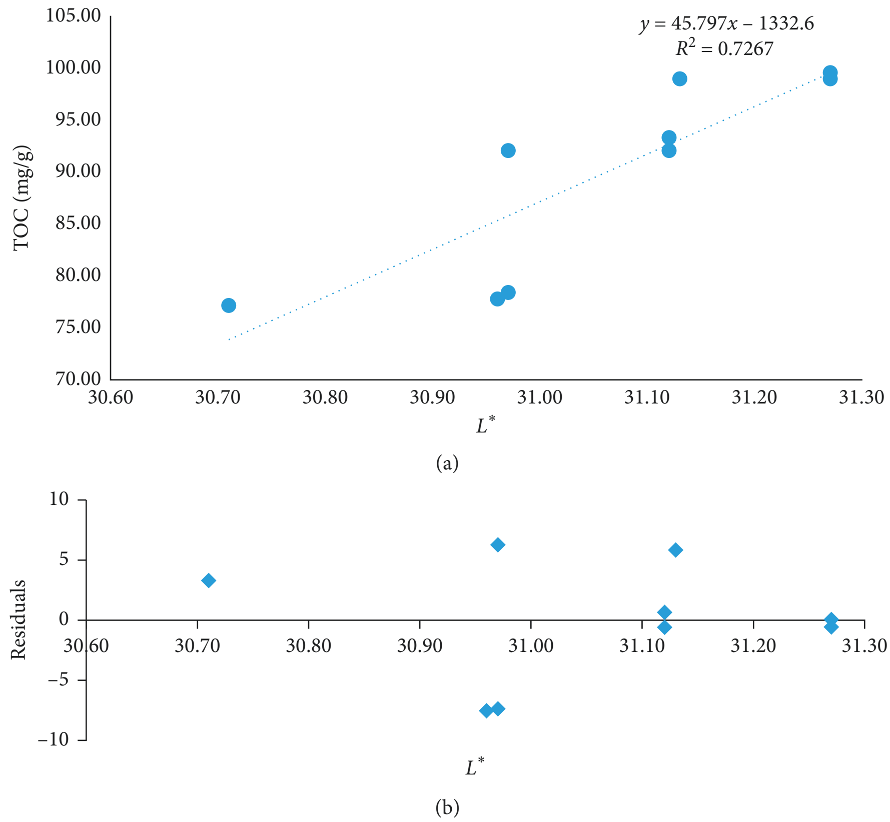

Figure 3: (a) Correlation TOC versus L^* coordinate for compost at a particle size of 2 mm and (b) residuals plot.

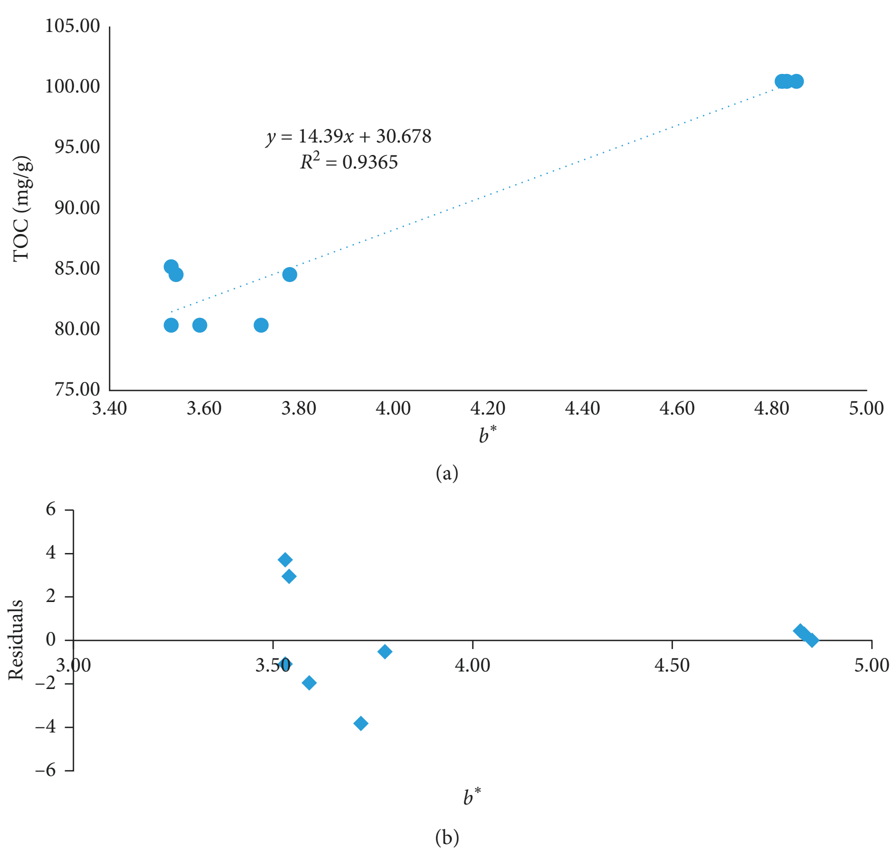

Figure 4: (a) Correlation TOC versus b^* coordinate for compost at a particle size of 2 mm and (b) residuals plot.

the statistical software SPSS Statistics Version 20. The correlation between the CIE$_{L^*a^*b^*}$ coordinates and the TOC content was performed using the methodology proposed by Khan et al. [13]. For this purpose, SPSS Statistics V 20 software was used, graphically supporting the office package software, Excel.

3. Results and Discussion

3.1. Estimation of COT by Spectrophotometry. For this test, the COT of compost was supplied by the La Rejoya farm of the Universidad del Cauca. Table 1 presents a summary of the data obtained for each particle sizes used. At first glance, a variability in the carbon content is observed in each of the three particle sizes employed. Figure 1 shows the behavior of the results obtained, where the highest TOC content was obtained for the particle size of 1 mm with a mean of 93.59 mg/g, followed by the particle size of 0.5 mm with a mean of 89.78 mg/g, and the lowest content was registered for the particle size of 2 mm with a mean of 88.54 mg/g. For a sample of soil with similar particle size, taken from Villa de Leyva (Boyacá), they report a carbon content of 93.40 mg/g, a value close to that obtained for the compost of La Rejoya [11], analogous for a size smaller than 2 mm, and they report a TOC of 48.90 mg/g [13]. Statistically, with a confiability of 95%, it was established that if there is a significant difference between the content of the TOC for the three particle sizes, the size apparently affects the estimate of the TOC. For this reason, we work with particle sizes of 0.5 mm and 2 mm in the CIE$_{L^*a^*b^*}$ determination.

3.2. Determination of Coordinates CIE$_{L^*a^*b^*}$. Table 2 shows the total organic carbon (TOC) concentration and the CIE$_{L^*a^*b^*}$ color of the compost samples evaluated in the present study. The particle size did not significantly affect the TOC concentration in the evaluated samples. The concentration of TOC in the samples agrees with that reported by Garcia Galvis and Ballesteros González [11] who, for the same particle size, reported a TOC of 93.40 mg/g. In contrast, Khan et al. [13] showed values below a size smaller than 2 mm (TOC = 48.90 mg/g).

Regarding the surface color, the particle size affects statistically all the color attributes evaluated in the samples (Table 2). The brightness (L^*), value a^*, and chromaticity (C^*) increases as the particle size decreases; on the contrary, the variables b^* and h° are reduced as the particle size increases (Table 2). These results agree with those expressed by Sánchez-Marañón et al. [16] who claim that solid materials such as compost generate an increase in luminosity as the particle size decreases when reducing the spaces between the particles. Li et al. [17] also support the results obtained in the present work, when expressing that the differences of the particle size in the samples cause significant variations in the perception of the color when determining the CIE$_{L^*a^*b^*}$ coordinates.

3.3. Correlation between TOC Content and CIE$_{L^*a^*b^*}$ Coordinates. Table 3 presents the Pearson correlations and the regression equations obtained by particle size; in the samples with a size 0.5 mm, a strong correlation ($r > 0.95$) between the TOC content and the coordinate a^* ($r = -0.992$ and $R^2 = 0.985$) was observed, and the regression value allows to state that 98.50% of the variation of the TOC content can be explained by changes in the color attribute a^*; therefore, the regression equation presented in Table 3, and Figure 2(a)), allows predicting the TOC in the 0.5 mm samples and in the Figure 2(b)), presented the residuals plot. While for the coordinate L^* ($r = 0.852$ and $R^2 = 0.727$), this regression value showed that 72.67% of the variation of the TOC can be explained by the variability in the luminosity L^*. In Table 3 and Figure 3(a)), presented TOC and in Figure 3(b)), presented the residuals plot.

In the case of the 2 mm samples, the correlation is strongly significant ($r > 0.95$) between TOC and the tristimulus value b^* ($r = -0.968$ and $R^2 = 0.94$), the regression value obtained indicates that 94% of the variation of the TOC content can be explained by the changes in the color attribute b^*, and therefore, the COT can be estimated by the regression equation presented in Table 3 and Figure 4(a) and in Figure 3(b), presented the residuals plot.

Similar studies carried out by Khan et al. [13] confirm the existence of high correlation values between CIE$_{L^*a^*b^*}$ and TOC, outstanding b^* with $r = 0.962$–0.985, C^* with $r = 0.957$–0.982, and h° with $r = 0.051$–0.957.

4. Conclusions

In this study, it can be concluded that the particle size affects the color perception in the compost. Strong correlations between total organic carbon and CIE$_{L^*a^*b^*}$ were identified, and the coordinates a^* ($r = \mathbf{-0.992}$), L^* ($r = \mathbf{0.852}$), and b^* ($r = \mathbf{0.968}$) have the potential to be used in estimating the concentration of total organic carbon in the compost samples analyzed.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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