PHYSICAL AND MECHANICAL PROPERTIES CORRELATION OF COFFEE FRUIT (*Coffea arabica*) DURING ITS RIPENING

CORRELACIÓN DE PROPIEDADES FÍSICAS Y MECÁNICAS DEL FRUTO DE CAFÉ (*Coffea arabica*) DURANTE SU MADURACIÓN

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ABSTRACT: There were correlated CIELAB color coordinates and reflectance in the visible spectrum of the exocarp of *Coffea arabica* coffee fruits of the Colombia variety in 9 different development stages, with physical properties such as fresh and dry mass, moisture content, and diameters; and mechanical properties such as detaching tensile force, fracture force, firmness, deformation, and fracture energy in the breaking point. A multivariate linear regression analysis was run to obtain models to accurately predict properties of the coffee fruit from the chromatic coordinates (a* and/or b*) or reflectance for discriminating wave lengths of different stages of development of the coffee fruit, with a confidence level of 99% and an R^2 between 78.5 and 99.9%. Results could be used for the design of harvesting and classification systems, as well as for a rapid determination of coffee quality.

KEYWORDS: *Coffea arabica*, color, reflectance, physical properties, mechanical properties

RESUMEN: Se correlacionaron las coordenadas del espacio de color CIELAB y la reflectancia en el espectro visible del epicarpio del fruto de café *Coffea arabica*, variedad Colombia, de 9 diferentes estados de desarrollo, con propiedades físicas como masa fresca y seca, contenido de humedad y diámetros, y propiedades mecánicas como fuerza de desprendimiento del fruto, firmeza, fuerza de fractura, deformación y energía requerida para fracturar la pulpa. Utilizando análisis de regresión lineal multivariado se obtuvieron modelos que predicen significativamente propiedades del fruto de café a partir del conocimiento de las coordenadas cromáticas (a* y/o b*) o de la reflectancia para diferentes longitudes de onda discriminantes de estados de desarrollo, con un nivel de confianza del 99% y un R^2 entre 78,5 y 99,9 %. Los resultados obtenidos podrían ser utilizados para el diseño de sistemas de recolección, clasificación y determinación rápida de la calidad del café.

PALABRAS CLAVE: *Coffea arabica*, color, reflectancia, propiedades físicas, propiedades mecánicas

1. INTRODUCTION

In order to improve the coffee fruit (*Coffea arabica*) processing, different physical [1–3] and mechanical properties [3–6] have been investigated. Some authors [7–11] have measured fruit color using different color models as well as subjective and quantitative measurement methods, depending on each study: RGB; Royal Horticultural Society Colour Chart; Pantone color chart; normalized reflected light peak; image processing to measure: RGB, HSI, YIQ, YCbCr, Ohta color spaces; and opponent color models. The CIELAB color spacing is a Cartesian coordinate system defined by three rectangular coordinates (L*, a*, b*); L* is the lightness (L*= 100, white; L*= 0, black), a* is from green (-a*) to red (+a*), and b* is from blue (-b*) to yellow (+b*).

However, color measurement using the CIELAB for coffee fruits of the variety Colombia, or reflectance in the visible spectrum have not been reported, and the latter is a conventional method for describing the color of any object. Neither has the color been associated with physical properties such as mass, moisture content, size, or mechanical properties such as detachment force, firmness, fracture force, deformation, or fracture energy, which are measurements obtained by destructive tests applying compressive stress.

Studies exist in other fruits where the colorimetry has been related to other properties. For example, [12] non-destructive estimation of pigments with spectral reflectance in apple fruit was obtained; [13] the CIELAB color was correlated with texture and concentration of carotenoid in tomatoes; [14] color in CIELUV and CIELAB spaces were measured and related to pigments in olives; [15] spectral wavelengths were identified to determine skin defects in citrus fruit; and [16] the relation between physical, mechanical, and chemical properties in different stages of the ripeness of banana.

In order to satisfy the demands of coffee drinkers, it is important and interesting to know the relation between different physical and mechanical properties via color of fruit, which are closely associated with grain quality. The aim of this study was to correlate the color coordinate of CIELAB and reflectance (in the visible spectrum, 400 to 700 nm) of the epidermis of coffee fruits of the Colombia variety to different physical and mechanical properties for 9 stages of ripeness.

2. MATERIALS AND METHODS

This research was carriedout at theExperimental station *El Rosario* of *Centro Nacional de Investigaciones de Café,* CENICAFE, located in the municipality of Venecia, Antioquia-Colombia(05° 58’ north latitude, 75° 43’west longitude,and 1,630 maltitude, average temperature of 20.1ºC) and in the laboratories of the Agricultural Process and Quality Controlat the *Universidad Nacional de Colombia, Sede Medellín*.

A plot of *Coffea arabica* L. Colombia variety under full sun exposure was used, with adistance of 1 m x 1 m, planted in May of 1999 and renewed by stumpingin February 2006. One hundred two *trees were randomly selected* and the main *flowering, which was held on April 18 of 2009, was marked.* With the scale for measuring fruit ripeness used by [3], there were 9 different stages of fruit development defined as 182, 189, 196, 203, 210, 217, 224, 231, and 238 days after blossom DAA, Table 1) the physical and mechanical properties were measured for each stage of development as shown in Table 2, using the methodology and procedures evaluated by [4,17–19].

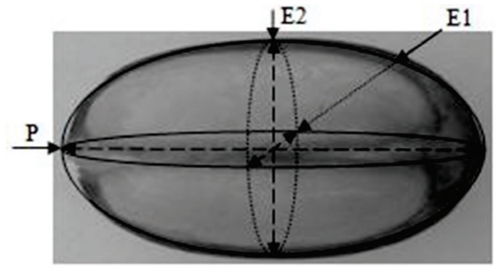


Figure 1. Diameters and symmetry planes of the coffee cherryfruit

With the average values for each one of the properties of coffee fruits cherries evaluated in 9 stages of fruit development, the correlation of the coordinates L*, a*, b*, and reflectance with mechanical and physical properties were performed, using multivariate linear model analysis with the Statgraphics®statistical software version 5.1.

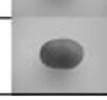
Characteristic diameter was also correlated with physical and mechanical properties. Correlations were performed at a confidence level of 99%. For each equation, the significance level P of the model, the standard error of estimation,and the coefficients of determination were obtained.

3. RESULTS AND DISCUSSION

3.1. Correlation of physical and mechanical properties with the chromaticity coordinates color CIELAB.

Table 3 presents results for each of the regression models of the form $Y = C_0 \pm C_1{\cdot}L^* \pm C_2{\cdot}a^* \pm C_3{\cdot}b^*$predicting properties of coffee fruit from the knowledge of chromaticity coordinates a* and b*.

Table 1. Stages of development of coffee fruit Colombia variety

DAA	Sampling	Fruit	Average color
182			
189			

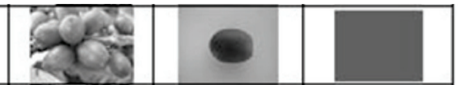
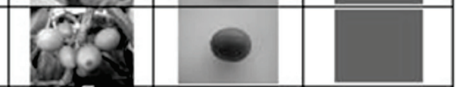
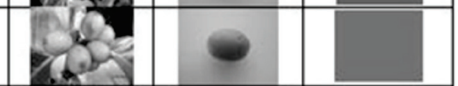
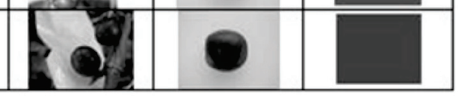
196	
203	
210	
217	
224	
231	
238	

Table 2. Properties evaluated for each stage of development of coffee fruit Colombia variety

Properties	Variable	Units	Measuring instrument	Sample size	Comments
Physical	Coordinates L*, a*, b*	Dimensionless	Sphere spectrophotometer	300 fruits (900 records)	3-point measurement of the fruit by rotating 90° around its the longitudinal axis center
	Reflectance	%			Reflectance curve in the visible spectrum (400 ≤ λ ≤ 700 nm)
	Equatorial (E1, E2) and Polar (P) diameters	mm	Digital caliper, references [4,17–18]	100 fruits	As defined in Fig. 1
	Characteristic diameter (Dc)	mm	Mathematical formula, references [4,17–18]	100 fruits	Calculated from E1, E2, and P
	Fresh mass (M), Dry mass (Ms)	g	Balance	20 fruits	Five replications
	Moisture content (Mc)	% w. b.	Gravimetric method, reference [19]		Oven at 105 °C for 48 hours
Mechanical	Detaching tensile force (Ft)	N	Portable digital dynamometer, reference [4]	100 fruits	Applied in the direction of the peduncle plane (P)
	Firmness with parallel plates	N/mm	Texture analyzer in compressive mode, reference [6] -Load cell: 50 kg -Speed frame: 1.7 mm·s-1 -Maximum deformation: 6 mm Contact of the fruit with plane surface with 2 attachments to apply force -Sharp tip (Ø: 3 mm) -Parallel plates (Ø: 100 mm) Fruits were placed according to planes in Fig. 1	50 fruits	Relation between fracture force and deformation. Planes E1, E2, P
	Firmness with sharp tip	N/mm			Planes E1, E2
	Unitary deformation with sharp tip	mm·mm-1			Relation between deformation and dimension recorded upon reaching the pulp fracture at the E1, E2 planes
	Unitary deformation with parallel plates	mm·mm-1			Planes E1, E2, P
	Fracture force with parallel plates	N			Planes E1, E2, P
	Fracture force with sharp tip	N			Planes E1, E2
	Fracture energy with sharp tip	N·mm			Area under force-deformation curve in planes E1,E2, P
	Fracture energy with parallel plates	N·mm			Planes E1, E2, P

Luminosity L* showed no significant effect in predicting different properties. Properties that showed highest fit (R^2) of the linear model with the chromatic variables are shown as well. For all mechanical and physical properties studied, except for deformation with plates in plane E1, polar diameter (P) and moisture content of fruits (Mc), a *significant linear relationship* with the *chromaticity coordinates* a* or b*, or with both, was found. According to Table 3, some physical and mechanical properties (Y) can be explained with the monochrome knowledge a* or b* and other variables with a*and b* bichrome coordinates. For example, fruit size, expressed through the equatorial diameter (E1, E2) and the characteristic diameter (Dc) can be estimated knowing the chroma a* indicating whether the fruit is ripe (red, a* > 0) or unripe (green, a*< 0). Fracture force and fruit pulp firmness properties measured with sharp tip in the equatorial plane E1 are those that can be predicted with better explanation (R^2 > 99%) from a* and b* color of the skin of coffee fruit between 182 and 238 days of development. For the rest of properties, the explanation for their color variation ranged between 78.5 and 98.6%. Fruit size (E2 and E1) can be predicted from a* with a correlation of 95.34 and 89.43%, respectively. The fresh and dry mass of coffee fruits can be predicted from a* and b* and with a correlation of 92.1 and 78.5%, respectively. The fracture force in the equatorial plane E2 can be estimated from the chroma a*, with a correlation of 97.9%, and the tensile force required to detach the fruit can be predicted from chroma a* and b*, with a correlation of 88.9%.

3.2. Physical and mechanical properties correlation with reflectance (%)

Multiple linear regression models of physical and mechanical properties with reflectance were evaluated for wavelengths (λ) of 550, 590, 640, 670 and 700 nm in which the highest discrimination of ripening stages of coffee was obtained. Results for each model of the form $\boldsymbol{Y = C_0 \pm C_1 \cdot \lambda_{550} + C_2 \cdot \lambda_{590} \pm C_3 \cdot \lambda_{640} \pm C_4 \cdot \lambda_{670} \pm C_5 \cdot \lambda_{700}}$ are shown in Table 4.

Table 3. Correlation between physical and mechanical properties with CIELAB coordinates of coffee fruits, Colombia variety

Property *Y*	C_0	C_1 of L*	C_2 of a*	C_3 of b*	P** Value	R^2 (%)	Estimated standard error
Fracture force with sharp tip, E1	31.6343	0.0000	-1.82869	1.31492	0.0000	99.6561	1.91074
Firmness with sharp tip, E1	17.6917	0.0000	-1.30895	1.02464	0.0000	99.0184	2.39598
Fracture force with parallel plates, P	90.1299	0.0000	- 4.90065	5.75077	0.0000	98.6141	13.419
Firmness with parallel plates E2	20.6327	0.0000	- 0.943797	1.65419	0.0000	98.4935	3.32248
Fracture energy with parallel plates, P	198.587	0.0000	- 14.7862	13.5758	0.0000	98.4231	38.8652
Deformation with parallel plates, E2	2.40575	0.0000	- 0.0171519	0.0546396	0.0000	98.3158	0.0941918
Firmness with parallel plates, P	21.6954	0.0000	- 0.821096	1.26819	0.0000	98.2541	2.90332
Fracture force with parallel plates, E1	85.8635	0.0000	- 4.92923	6.83162	0.0000	98.1449	16.9806
Fracture force with parallel plates, E2	61.3826	0.0000	- 4.44229	6.92797	0.0000	98.1376	16.3186
Fracture force with sharp tip, E2	56.8737	0.0000	-2.2729	0.0000	0.0000	97.8730	3.4605
Firmness with parallel plates, E1	26.1827	0.0000	- 1.36937	1.89898	0.0000	97.8022	5.14506
Deformation with sharp tip, E1	2.50768	0.0000	0.0000	- 0.0408582	0.0000	96.8894	0.0662094
Fracture energy with sharp tip, E1	43.5908	0.0000	- 1.8359	0.0000	0.0000	95.5385	4.09738
Equatorial diameter, E2	13.3408	0.0000	0.0816535	0.0000	0.0000	95.3439	0.213071
Deformation with sharp tip, E2	2.50243	0.0000	0.0000	- 0.041898	0.0001	94.008	0.0956645
Deformation with parallel plates, P	4.15467	0.0000	-0.0562264	0.0000	0.0000	92.2243	0.192784
Fresh mass, M	1.5096	0.0000	0.0204697	0.0000	0.0000	92.077	0.0709026
Firmness with sharp tip, E2	43.2864	0.0000	- 2.55945	0.0000	0.0003	90.7547	8.43684
Characteristic diameter, Dc	13.5782	0.0000	0.0533153	0.0000	0.0001	90.2509	0.206915
Fracture energy with parallel plates, E2	398.667	0.0000	- 20.4794	0.0000	0.0001	89.6552	82.1434
Equatorial diameter, E1	11.8575	0.0000	0.0544554	0.0000	0.0001	89.4333	0.221027
Detaching tensile force, Ft	3.77088	0.0000	0.142688	0.379572	0.0014	88.8805	0.817438
Fracture energy with parallel plates, E1	396.645	0.0000	- 18.5615	0.0000	0.0002	88.5999	78.6199
Fracture energy with sharp tip, E2	46.8793	0.0000	- 1.55753	0.0000	0.0014	83.7985	7.073
Dry mass, Ms	0.642653	0.0000	0.0000	- 0.00803943	0.0015	78.4946	0.0374106
Deformation with parallel plates, E1	3.41643	0.0000	- 0.0140383	0.0000	0.0154	59.1568	0.137739
Polar diameter, P	17.9847	- 0.0800881	0.0246218	0.0538937	0.2037	57.1349	0.306094
Moisture content, Mc	79.9505	- 0.542461	0.16881	0.543037	0.2113	56.4347	1.27553

**If P < 0.01, there is a significantrelationship between independent variables at 99% confidence level

Table 4. Physical and mechanical properties correlation with reflectance for discriminating wavelengths (λ)of coffee fruits, Colombia variety

Property *Y*	C_0	C_1 of λ_{550}	C_2 of λ_{590}	C_3 of λ_{640}	C_4 of λ_{670}	C_5 of λ_{700}	P** Value	R^2 (%)	Estimated standard error
Equatorial diameter, E2	18.6913	- 0.962148	1.55078	- 0.903061	0.416552	- 0.148226	0.0000	99.9918	0.0136266
Firmness with sharp tip, E1	67.6334	4.41839	0.0000	4.76987	0.0000	-5.75543	0.0000	99.9312	0.709404
Fracture force with sharp tip, E1	211.143	- 20.1783	32.006	- 20.1023	0.0000	0.0000	0.0000	99.9218	1.01888
Deformation with sharp tip, E1	1.03607	- 0.102837	0.0000	- 0.170371	0.0000	0.162304	0.0001	99.9211	0.0129165
Equatorial diameter, E2	17.9763	- 0.995502	1.47146	- 0.969868	0.334952	0.0000	0.0000	99.8535	0.0499917
Fracture force with sharp tip, E1	86.6912	5.46509	0.0000	4.69611	0.0000	-6.26981	0.0000	99.7728	1.73631
Fracture force with sharp tip, E2	195.261	- 16.0351	24.7099	- 16.3885	0.0000	0.0000	0.0000	99.5298	1.99281
Equatorial diameter, E1	15.3894	- 0.838076	1.30093	- 0.898714	0.336468	0.0000	0.0001	99.411	0.0690293
Firmness with parallel plates, E2	67.4753	5.10602	0.0000	5.58095	0.0000	5.99508	0.0000	99.257	2.55596
Fresh mass, M	3.54029	-0.389887	0.580395	-0.38225	0.111315	0.0000	0.0003	99.0385	0.0326751
Fracture force with parallel plates, E2	280.831	22.4555	0.0000	24.9326	0.0000	27.2635	0.0000	99.0255	12.9306
Characteristic diameter, Dc	18.9869	- 1.04521	1.56533	- 1.04602	0.315091	0.0000	0.0003	98.9945	0.0879064
Fracture force with sharp tip, E2	80.1938	2.98238	0.0000	0.0000	0.0000	-2.42229	0.0000	98.8259	2.81648
Firmness with parallel plates, E1	109.692	6.77263	0.0000	8.56262	0.0000	9.46693	0.0000	98.6269	4.45494
Firmness with sharp tip, E2	93.5448	0.0000	6.73299	0.0000	0.0000	- 4.95829	0.0001	98.0797	4.21201
Fracture force with parallel plates, E1	308.473	22.0422	0.0000	22.4759	0.0000	-26.0226	0.0001	98.0501	19.0707
Deformation with parallel plates, E2	4.28038	0.0000	0.165312	0.0000	0.0000	- 0.107859	0.0000	97.8106	0.107395
Fracture energy with sharp tip, E1	52.5828	2.55029	0.0000	0.0000	0.0000	- 1.68951	0.0001	97.0785	3.63215
Firmness with parallel plates, P	29.6842	2.72694	0.0000	0.0000	0.0000	- 0.893206	0.0000	97.3801	3.55655
Fracture force with parallel plates, P	155.163	13.7521	0.0000	0.0000	0.0000	- 5.8155	0.0000	97.3251	18.643
Firmness with sharp tip, E2	31.9261	3.91008	0.0000	0.0000	0.0000	-1.71383	0.0002	96.7179	5.50663
Fracture energy with parallel plates, P	498.177	0.0000	41.6354	- 43.7805	0.0000	0.0000	0.0000	96.6701	56.4769
Fracture force with parallel plates, E1	156.064	15.1076	0.0000	0.0000	0.0000	- 5.99072	0.0000	96.64	22.8527
Fracture energy with parallel plates, E2	326.393	0.0000	41.6189	- 36.1885	0.0000	0.0000	0.0000	96.3674	52.5771
Fracture energy with parallel plates, E1	319.694	0.0000	38.3193	- 32.5683	0.0000	0.0000	0.0001	95.8043	51.5174
Detaching tensile force, Ft	14.7536	0.844318	0.0000	1.81785	0.0000	-1.46611	0.0011	95.0808	0.595596
Deformation with parallel plates, E2	1.81658	0.0000	- 0.101469	0.0000	0.0000	0.0443339	0.0006	95.017	0.0955651
Fracture energy with sharp tip, E2	93.8004	1.60113	0.0000	0.0000	0.0000	- 2.50018	0.0015	92.5006	5.27145
Fracture energy with sharp tip, E2	93.8004	1.60113	0.0000	0.0000	0.0000	- 2.50018	0.0015	92.5006	5.27145
Fresh mass, M	1.8088	- 0.0490313	0.0336649	0.0000	0.0000	0.0000	0.0004	92.3767	0.0751215
Deformation with parallel plates, P	5.76087	0.0000	0.146659	0.0000	0.0000	- 0.127118	0.0005	92.3351	0.206741
Polar diameter, P	24.0606	- 1.33164	1.96217	- 1.29121	0.266815	0.0000	0.0399	87.9676	0.181315
Dry mass, Ms	0.338149	0.0000	0.0000	0.0000	0.0121682	0.0000	0.0003	85.8893	0.0303038
Moisture content, Mc	77.5628	- 0.988361	0.0000	0.0000	- 1.33848	0.762142	0.0460	77.2599	0.921544
Deformation with parallel plates, E1	2.51942	0.0000	0.0000	- 0.08407	0.0000	0.0722391	0.0138	75.9978	0.11405

**If $P < 0.01$, there is a significantrelationship between independent variables at 99% confidence level.

A statistically significant linear correlation with different wavelengths (550 ≤ λ ≤ 700 nm) was found for all mechanical and physical properties studied, except for the polar diameter (P), moisture content, and deformation with parallel plates in E1. Firmness and fracture force properties of fruit measured with a sharp tip on the equatorial plane E1, equatorial diameter (E1 and E2), deformation with sharp tip E1, fracture force with sharp tip in E1, fracture force with sharp tip in E2, and firmness between parallel plates in the plane E2, can be predicted with a major explanation (R^2 > 99%) from the reflected light at different wavelengths for fruits from 182 to 238 days of development. For the remaining properties, the explanation of their variability with regard to reflectance ranged between 92.33 and 98.99%. The equatorial diameter E2 was the property that presented a higher correlation with the reflectance of the fruit. This physical property associated with the fruit size is significantly correlated to light reflected in the green-yellow, yellow-orange, orange-red, and red regions of the visible spectrum. Firmness using sharp tip in the equatorial plane E1, mechanical property indicator of fruit resistance, is also significantly correlated to light reflected in the green-yellow, orange-red, and red regions of the visible spectrum. The greater the reflected light from the fruit surface in the first regions of the spectrum, reflecting more in the red (700 nm), the lower the firmness will present itself, and therefore the more ripe the fruit will be.

Similar analysis can be performed for the model predicting the detachment force and fracture force according to the light reflected from the fruit surface in different regions of the visible spectrum.

3.3. Physical and mechanical properties correlation with the characteristic diameter (Dc)

Table 5 shows linear models of the form *Y = Intercept ± Slope*Dc*, that relate different physical and mechanical variables to the characteristic diameter (Dc) of coffee fruitsduring their stage of ripeness. It wasfound that Dc is not correlated with: the moisture content, the fracture energy with sharp tip in the E2 plane, the deformation with plates in E1, or the detaching force (Ft).The other properties were significantly correlated ($P < 0.01$) to Dc at a confidence level of 99% and with the R^2 ranging between 78.2 and 99.6%. It was found that fresh mass (M) is the most closely related variable to Dc with a correlation coefficient of 99.57%. According to Table 5, the deformation between parallel plates in the three compressive planes decreases during ripening. The opposite case was found for fruit deformation with a sharp tip, which increases with the ripeness in both different compressive planes.

Table 5. Physical and mechanical properties correlation to the characteristic diameter (Dc) of coffee fruit, Colombia variety

Property *Y*	*Intercept*	*Slope of Dc*	*P** Value*	*R² (%)*	*Estimated standard error*
Fresh mass, M	-3.64037*	0.379292	0.0000	99.5701	0.0165155
Fracture force with sharp tip, E1	770.255	- 52.6241	0.0001	93.3174	7.68909
Fracture energy with sharp tip, E1	507.576	- 34.2164	0.0001	92.7537	5.22185
Firmness with sharp tip, E1	563.661	- 38.8243	0.0002	92.2081	6.16227
Fracture energy with parallel plates, P	6092.45	- 414.474	0.0000	91.8856	81.6227
Deformation with parallel plates, P	17.6709	- 0.99558	0.0001	91.0685	0.206615
Fracture force with parallel plates, P	2263.25	- 151.74	0.0001	90.7907	32.0261
Deformation with sharp tip, E1	-7.14239	0.654787	0.0003	90.7006	0.114478
Dry mass, Ms	-1.08504	0.115554	0.0001	90.1037	0.0253781
Fracture force with parallel plates,, E1	2454.34	- 164.565	0.0001	89.2704	37.808
Firmness with parallel plates, E1	685.08	- 45.7831	0.0001	89.162	10.5779
Firmness with parallel plates, E2	537.846	- 35.7008	0.0001	89.121	8.26591
Firmness with parallel plates, P	439.939	- 28.9704	0.0001	89.0621	6.72797
Fracture force with parallel plates, E2	2331.78	- 157.2	0.0002	88.5491	37.4618
Fracture force with sharp tip, E2	610.252	- 40.7991	0.0005	88.1427	8.17052
Deformation with parallel plates, E2	16.4004	- 0.951624	0.0002	88.0758	0.232039
Firmness with sharp tip, E2	689.91	- 47.6848	0.0006	88.0484	9.5925
Fracture energy with parallel plates, E2	5303.76	- 361.302	0.0002	87.8889	88.88
Fracture energy with parallel plates, E1	4847.14	- 327.816	0.0002	87.0404	83.8253
Deformation with sharp tip, E2	-6.87234	0.632802	0.0036	78.164	0.182621
Fracture energy with sharp tip, E2	409.345	- 26.7158	0.0107	68.91	9.79798
Deformation with parallel plates, E1	6.80593	- 0.24966	0.0157	58.9283	0.138124
Detaching tensile force, Ft	38.7579	- 2.02678	0.0932	35.0231	1.82944

**If $P < 0.01$, there is a significant relationship between independent variables at 99% confidence level

Models indicate that firmness, independent of the attachment used (sharp tip or parallel plates), is inversely proportional to Dc. This corroborates with what was expected, the fruit, having developed, increases in size and becomes softer up to the overripe stage, when it is close to drying off in the tree, the Dc diminishes, and the firmness is less. A similar trend was found by [20] in pears: as the fruit grows its firmness diminishes. The other mechanical properties (fracture force and energy)also diminish when the fruit size is increased. The Dc variable is not correlated to moisture content or the fruitdetachment force. For the fracture energy variable with a sharp tip on the E2 plane, fracture deformation with parallel plates on the E1 plane, and deformation with a sharp tip on the E2 plane, the R^2 changed between 58.9 and 68.9%. The rest of the variables were correlated to the diameter Dc at a confidence level of 99% ($P < 0.01$). Firmness and fresh mass evaluated at [3] did not demonstrate correlation with Dc. Those differences with this work could be explained by the methodology used in both studies.

4. CONCLUSIONS

Different linear models with a confidence level of 99% and a correlation that changed between 78.5 and 99.9%, allow for one to predict different physical and mechanical properties of coffee fruits Colombia variety, with stages of development between 26 and 34 weeks from the knowledge of the chromatic coordinates (a* and b*) or from skin reflectance at different wavelengths.

Mechanical and physical properties studied (except for the deformation with plates in the plane E1, the polar diameter and moisture content of fruits)showed a significant correlation with chromaticity coordinates a*and b*.

Physical and mechanical properties of the coffee fruit are significantly correlated with reflectance, except for the polar diameter, dry mass, moisture content, and the deformation by fruit compression between plates in the equatorial plane.

Physical and mechanical properties of coffee fruit are significantly correlated to their characteristic diameter, except for moisture content, the fracture energy with sharp tip on the E2 plane, the deformation with plates at the E1, and the detachment force of the fruit.

Correlations found in this research could be used for the design of collecting and sorting systems and quick and accurate determination of the quality of coffee fruit Colombia variety.

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