Fruit quality in Hass avocado and its relationships with different growing areas under tropical zones[1]

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ABSTRACT

Avocado is currently an important crop in Colombia, given its growth in planted area and the increase in exports. The destination market of Colombian avocado is mainly international, and its quality is outstanding. However, the physical and chemical characteristics associated with the quality of the avocados produced are not currently well known in Colombia. The aim of this study was to evaluate the physical, chemical and nutritional parameters associated with the quality of Hass avocado in eight localities of the department of Antioquia based on descriptive statistics. Additionally, the quality was related to the localities through a multivariate analysis. As a result, quality at preharvest parameters of Hass avocados cultivated in Antioquia is similar or superior to that reported internationally based on physical and chemical variables. In addition, a relationship was established between the quality of fruits and the plots where these were cultivated, which allowed discriminating fruits by their region of origin. This work shows an approach to the determination of quality parameters in Hass avocado in Colombia and how they can be related to the characteristics of its productive system, which can lead to defining a product with added value.

Keywords: fatty acids; added value; planted area; multivariate analysis.

INTRODUCTION

The Hass variety of avocado (*Persea americana* Mill) can be highlighted as the most important one in terms of cultivated area, geographical distribution and consumption (Bost *et al.*, 2013). The Hass variety has been the most planted in Colombia with notable growth in cultivated area and production. This crop grows mainly in moderately cold climates, located between 1,400 and 2,600 meters above sea level (Ramírez-Gil *et al.*, 2018). The main reason for the increase in planted area with avocado is based on the growth of the international demand. This phenomenon is a consequence of the multiple health benefits consumers perceive in this fruit, in addition to its pleasant flavor (Pérez-Méndez & García-Hernández, 2007; Rodriguez-Sanchez *et al.* 2015; Monika & Geetha, 2015).

Despite the rapid growth of this productive system in Colombia, the industry has presented some technological limitations, constraints at the preharvest level associated with plant pathologies and insects, and problems in the selection of areas with appropriate soil and climatic conditions for planting this species (Torres-Jaimes *et al.*, 2015; Ramírez-Gil *et al.*, 2017; Ramírez-Gil *et al.*, 2018; Ramírez-Gil & Morales-Osorio, 2018). However, information on fruit quality parameters is poor and only some studies that describe the direct relationship between altitude and fatty acid profile, minimum dry matter index for an optimum harvest, and determination of some physical-chemical parameters of avocado fruits for export are reported (Carvalho *et al.*, 2014; Carvalho *et al.*, 2015; Astudillo & Rodriguez, 2018).

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It has been suggested that fruit acceptability is more correlated with texture, and taste with the oil content (Salazar-García *et al.*, 2016a; Salazar-García *et al.*, 2016b). In addition, it must be considered that quality is determined by multiple environmental factors, edaphic conditions, preharvest, harvest, and postharvest practices as well as geographical origins (Burdon *et al.*, 2013; Ferreyra *et al.*, 2016; Hernández *et al.*, 2016; Tan *et al.*, 2017). The biophysical, edaphic, environmental or management conditions in a productive system can give rise to a product with outstanding quality parameters, which can be used as a factor for market differentiation to increase the added value.

The fatty acid profile can be used as a biomarker or as a parameter to determine the suitable areas for avocado Establishment and the agronomic practices associated to this crop (Donetti & Terry, 2014; Ferreyra *et al.*, 2016; Tan *et al.*, 2017). Consequently, the aim of this research was to determine the physical, chemical and nutritional quality of avocado cv. Hass fruits grown in contrasting conditions of the department of Antioquia, as a basis for the determination of areas with outstanding characteristics for the production of fruits with high-quality standards.

MATERIAL AND METHODS

Location and sampling

Fruits were collected in eight commercial avocado cv. Hass plots certified by Instituto Colombiano Agropecuario (ICA) as export farms. Plots were located in three sub-regions of the department of Antioquia (Table 1): four in the east ("LA" in El Peñol, "EC" and "EG" in El Retiro and "LE" in Rionegro); two in the southwest ("IM" in Amaga and "BV" in Jardín) and two in the north ("CS" and "EB" in San Pedro de Los Milagros). In each plot, weather stations (WatchDog 2900ET series) were placed, which had sensors for environmental temperature (°C), relative humidity (%), soil temperature (°C), soil moisture (%), solar radiation (W/m^2), photosynthetically active radiation - PAR (ìmol m^{-2} s^{-1}) and precipitation (mm). Data were recorded every 15 minutes (Table 1).

In each plot, two trees with fruits were selected with known phenology and soil analysis and no visible presence of pests and diseases. From each tree, 25 fruits with a commercial size ranging from fruit caliber 18–20 (weight between 184 and 243 g; fruit with the most commercial caliber for Colombia) were harvested. These fruits were harvested with a dry matter percentage close to 23.5% ± 1.1 which was determined according to the method AOAC 934.01 (AOAC, 2016) to guarantee an excellent ripening quality (Carvalho *et al.*, 2014). After harvest, fruits were placed in a paper bag, labeled with the code of the farm, block, and tree. Then, they were delivered to the postharvest laboratory in Ríonegro Antioquia-Colombia 24 hours later.

Physical and chemical properties associated with Hass avocado fruit quality

Once fruits were received at the laboratory, the following physical variables were evaluated: equatorial and polar diameter (Redline mechanics digital caliper), fruit weight (Delta Range digital scale, Mettler PE 3600), and Hunter Lab tristimulus color, which was evaluated in the equatorial diameter of the fruit, excluding zones with damages or atypical colorations (portable colorimeter Konica Minolta, CR 400) (Henao-Rojas & Rodríguez, 2016).

Dry matter was previously evaluated by growers under field conditions (described before). Then, five random fruits were selected at the lab and dry matter was evaluated using the method AOAC 934.01 (AOAC, 2016). The remaining 20 fruits were stored in a refrigerated chamber (Supernordico, reference 430) for two weeks at an average temperature of 5 ± 2 °C and 80 ± 5% relative humidity. Subsequently, fruits were ripened in climatic incubators (Memmert HPP-110 at 20 ± 1 °C and 90 ± 2% relative humidity) until they reached consumption ripeness, which was determined at ripening level 5 following the methodology proposed by Gamble *et al.* (2010). The following evaluations were determined on these fruits: (i) color by the CIE Lab colorimetric method measured on

Table 1: Location and climatic conditions of the contrasting locations

Localities	Region	Elevation	Latitude	Longitude	Temperature (°C)			RH*	ASR**
		(m)	(N)	(W)	Max.	Mean	Min.	(%)	(W/m^2)
IM	Southeast	1753	06°012 423	75º402 423	32.7	21.6	6.9	69.2	417.7
LA	West	2009	06°112 403	75°132 593	30.4	18.7	8.6	78.0	480.8
BV	Southwest	2027	05°352 533	75°482 193	29.8	18.4	12.3	81.5	387.5
LE	East	2168	06°052 563	75°432 133	28.4	17.3	5.8	81.5	333.5
EG	East	2288	06°022 ‘513	75°292 423	27.4	16.0	2.7	82.6	436.3
CS	North	2396	06°292 433	75°312 133	27.2	15.4	2.5	79.8	438.2
EB	North	2453	06°292 263	75°312 283	24.2	15.3	3.7	77.3	421.9
EC	East	2448	06º012 423	75º272 253	26.9	15.6	3.6	76.6	433.4

*RH= relative humidity; **ASR= Accumulated solar radiation.

fruit epidermis, (ii) fruit mechanical resistance to penetration using a penetrometer (model FT 327, with a diameter of 5 mm), (iii) weight of each fruit using a digital scale (DeltaRange reference Mettler PE 3600), and (iv) epidermis, pulp, and seed percentage, according to AOAC 934.01 (AOAC, 2016); for dry ripe fruit weight, the same methodology used in firm fruits was followed (described before).

For chemical characterization, three random fruits were selected from each plot, which were homogenized and deep-frozen at -40 °C. These fruits were chemically characterized in terms of fatty acids and minerals by chromatographic techniques and atomic absorption spectrometry, respectively. For physicochemical and compositional parameters, the following protocols proposed by AOAC (AOAC, 2016) were used: humidity (AOAC, 2005), ash (AOAC 942.05, 2012), ethereal extract (AOAC 2003.06, 2012), protein (AOAC 960.52, 2012) and crude fiber (AOAC method 2009.01).

The elements phosphorus (P), potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg) were measured after acid digestion assisted by a microwave oven with a subsequent reading by plasma emission spectrometry (Sánchez-Castillo *et al.* 1998). The concentrations of iron (Fe), copper (Cu), manganese (Mn), boron (B), and zinc (Zn) were determined by acid digestion assisted by a microwave oven with a subsequent reading by atomic absorption spectrometry (Hofman *et al.*, 2002). Finally, nitrogen concentration (N) was determined by the Kjeldhal method 351.3 (EPA, 1974).

The quantification of palmitic, stearic, palmitoleic, oleic, arachidonic, linoleic and á-linoleic acids present in the samples was carried out using a gas chromatograph with a split/splitless injector and a flame ionization detector (FID), using the method described by Naik *et al.* (2008). Additionally, the determination of vitamin E was carried out based on an ultrasound-assisted liquid-liquid extraction with subsequent quantification using high-resolution liquid chromatography (HPLC) with a diode array detector (AOAC, 2016).

Data management and statistical analyses

For each of the evaluated variables, the central tendency, variance, and dispersion statistics were obtained. Additionally, hypothesis tests to fulfill assumptions, the Shapiro-Wilk test for normality, and Bartlett's test for homogeneity of variances were applied. To determine if there were differences between the localities in each of the studied variables, an analysis of variance (ANOVA) was applied to the variables that fulfilled assumptions of normality and homoscedasticity, followed by a Tukey multiple range test. On the other hand, the variables that did not fulfill these assumptions were subjected to the nonparametric Kruskal-Wallis test ($P \leq 0.05$).

In order to characterize and classify localities, two multivariate analysis techniques were used: factor analysis (FA) and discriminant analysis (DA). For FA, several methods of factor extraction were explored, selecting finally the classical factors method. Additionally, several oblique and orthogonal rotation methods were explored, selecting the orthogonal rotation method Varimax. To determine the minimum number of necessary factors, the factors with Eigen-values higher than one were initially considered. In addition, it was necessary that the cumulative proportion of the variance explained by the extracted factors was higher than 80% for the physical variables, and for the chemical variables, that the biological variation of the studied population was less than 30%.

For the discriminant analysis (DA) of both physical and chemical variables, linear relationships between the continuous variables were used to differentiate among previously defined categorical groups. In this case, the behavior of all the postharvest variables associated with fruit quality was analyzed in relation to the location they came from. The Lambda-Wilks parameter was chosen as a criterion for the selection of discriminatory factors, which should not be higher than 0.05.

RESULTS

Physical variables associated with Hass avocado quality and their relationship with the evaluated localities

Firmness, ripe fruit weight, and estimated volume showed higher values ($P < 0.05$) in the localities CS, EB, and EC, which were placed at a higher elevation and two of them were located in the northern region of Antioquia. At the same time, the localities of the southwestern region (BV and IM) presented the lowest values ($P < 0.05$) for these parameters. On the other hand, the apparent density showed slight variations between the localities, where the BV and CS plots presented low values ($P < 0.05$), and the EC plot was statistically higher (Table 2).

Regarding epidermis yields, the values ranged between 12-15% depending on the locality (Table 2), obtaining higher values ($P < 0.05$) at the IM locality, which has a higher temperature, lower relative humidity and was located at a lower elevation than other plots. Regarding pulp yield, values between 65 and 73% were found (Table 2). In terms of tristimulus colorimetry, fruits grown in the southwestern region have lower L* values, which represents darker greens, in addition to containing high blue tones (-b*), compared to the epidermis of the fruits grown in the other regions (Table 2).

Table 2: Range of different statistical comparative tests for physical variables associated with Hass avocado quality and its relationship with the evaluated localities

Variable	BV	IM	CS	EB	EC	EG	LA	LE	P-value	Comparative statistics
Firm fruit weight (g)	190.5a	184.4a	206.00bc	230.4c	217.8c	214.9bc	195.24ab	212.48bc	0	Kruskal-Wallis
Estimated volume (mL)	194.7ab	175.7a	215.19c	217.88c	202.70bc	209.17bc	194.30ab	202.89bc	3.93E-10	Kruskal-Wallis
Bulk density (g/mL)	0.99a	1.04bc	0.99a	1.04bc	1.07c	1.02bc	1.03b	1.04bc	0	Kruskal-Wallis
Ripe fruit weight (g)	182.0ab	175a	191.0bcd	211.0d	200.0cd	195.0bcd	186.0abc	198.0bcd	1.04E-07	Kruskal-Wallis
% of epidermis	12.64ab	15.03c	12.17a	13.74bc	12.63ab	12.78ab	15.08c	13.50bc	2.75E-10	Kruskal-Wallis
% of weigh loss	4.86b	3.33a	7.89cd	8.01d	8.48d	9.75d	4.99b	6.99c	0	Kruskal-Wallis
% seed	14.58abc	15.23ab	16.04a	16.06abc	16.69bc	17.51cd	18.04d	20.18c	0	ANOVA + Tukey
% pulp	65.02bc	68.70b	68.74c	69.74b	69.85b	70.22b	71.15a	73.02b	0	ANOVA + Tukey
L* Firm fruit	34.10a	35.25bc	36.44d	36.82cd	37.04c	37.79c	39.07ab	39.08d	0	ANOVA + Tukey
a* Firm fruit	-13.59c	-13.49bc	-12.25a	-12.11b	-12.01b	-11.81bc	-11.38b	-10.79a	0	ANOVA + Tukey
b* Firm fruit	15.25a	17.58b	17.77d	18.15cd	18.56bc	19.61bc	20.73bc	21.02d	0	ANOVA + Tukey
Ripe fruit texture (KgF)	1.76a	2.00b	2.38c	2.70d	1.90b	2.00b	2.10b	2.65d	0	Kruskal-Wallis

The percentage of weight loss during ripening was much more marked ($P < 0.05$) in fruits of a higher caliber and weight that came from localities with low temperatures, very high humidity and higher elevation (Table 1 and 2). For ripe fruit texture, the variability within regions was relatively low. However, considerable differences were observed among regions (Table 2).

Figure 1A shows the functions of the two factors that were used to relate the physical variables associated with Hass avocado quality. Factor 1 corresponded to a description of the avocado color and its behavior by locality. On the other hand, factor 2 indicates a function of the caliber, geometry, and percentage of fruit epidermis. These variables were fundamental to explain the variability of fruits in the studied region. The discriminant functions 1 and 2 showed Lambda-Wilks values of 0.0058 and 0.0278, respectively.

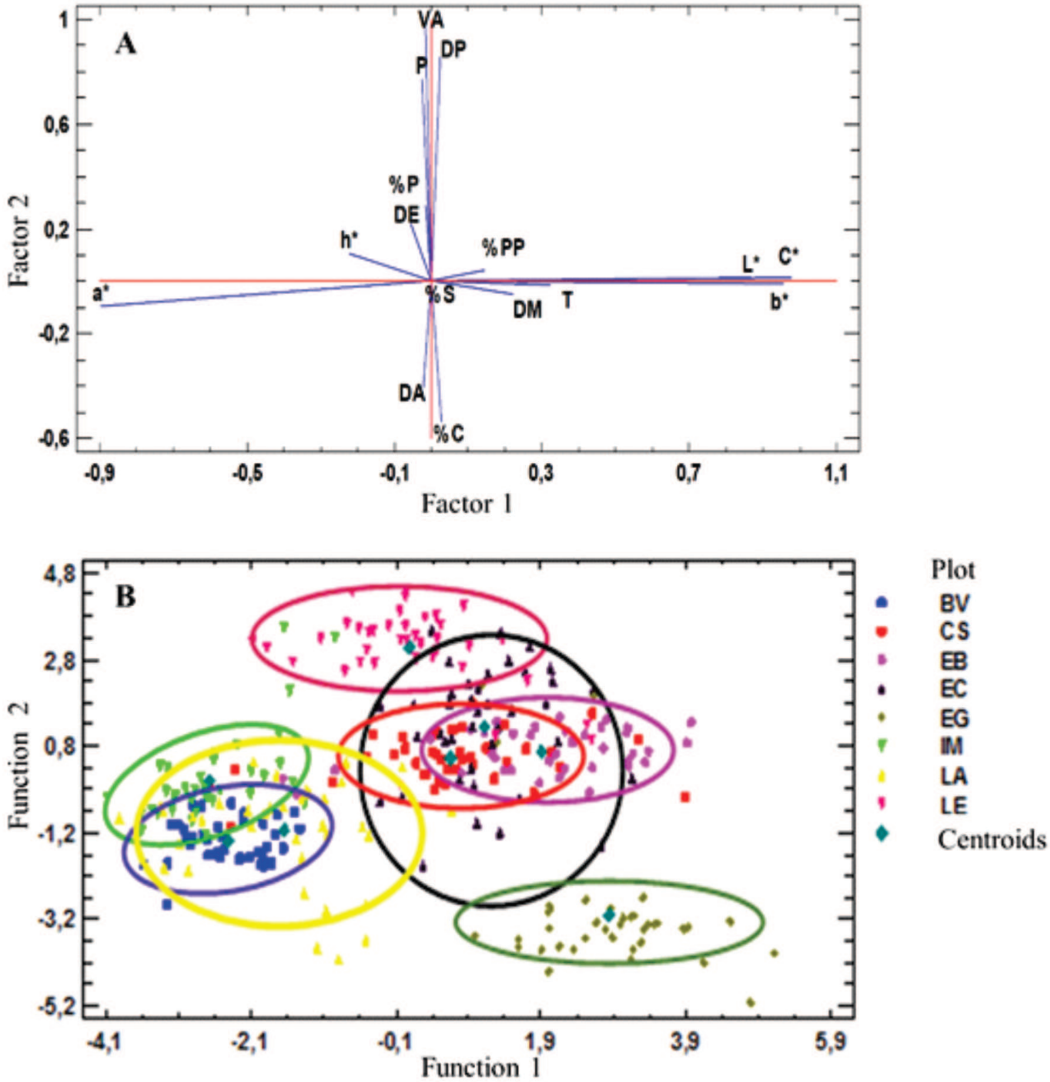
Figure 1B indicates that only one locality is homogeneous in terms of fruit physical characteristics; this high variability produces groupings by regions. The fruits from the northern region form a clearly defined cluster, with a similar behavior for the fruits from the southwestern region (BV, IM). However, in this region, fruits differ in their epidermis color and are similar in terms of caliber, weight, and yield. For the eastern region, the results are different; fruits from this region form individual clusters for each locality (EG and LE). In the particular case of the locality LA, fruits seem to behave as if they were from the southwestern region (localities BV and IM), and the fruits of the locality EC are so variable in terms of physical characteristics, that a clear grouping cannot be observed.

Chemical variables associated with Hass avocado quality and its relationship with the evaluated localities

Nitrogen concentration (N) behaved in a constant manner in the different assessed localities, with the exception of the locality IM, where it was lower ($P < 0.05$) than in the rest of localities. Phosphorus (P) concentrations did not show any differences between localities from the eastern region; in localities BV and EB, P concentrations remained within the before-mentioned range, whereas localities IM and CS had lower and higher P concentration values, respectively. The concentrations of potassium (K) and calcium (Ca) did not show differences ($P > 0.05$) among any of the localities. Magnesium concentration (Mg) presented the highest concentration ($P < 0.05$) in eastern localities. In addition, the northern and southwestern localities did not show differences in their Mg concentrations ($P > 0.05$), and the lowest Mg value ($P < 0.05$) was observed in the locality IM (Table 3).

On the other hand, sodium (Na) and sulfur (S) concentrations did not show differences (P > 0.05) among most of the evaluated localities. The iron (Fe) content only showed differences in the localities IM and CS, contrary to all the others did not show differences. The copper (Cu) content showed differences (P < 0.05) among all localities, except for EC and EG; however, there was no appreciable trend of this variable per locality or sub-region. Manganese (Mn) concentration showed a stable concentration in most of the localities, with the exception of EB, where it presented higher values. Zinc (Zn) concentration was grouped into two localities, BV, CS, EB, EG, and LA, which showed higher values (P < 0.05), whereas IM, EC, and LE had 50% lower values (P < 0.05). In addition, boron (B) concentration showed no differences among all the localities, except for the plots located in the northern region, which were substantially higher (P < 0.05) (Table 3). On the other hand, ash concentration, ether extract, and protein concentration showed no differences (P > 0.05) among localities. However, the case was different for the variable crude fiber, which showed higher values (P < 0.05) in fruits grown in the southwestern region (BV and IM). Vitamin E did not show statistical differences (P > 0.05) between the studied localities (Table 3).

According to the lipid profile, palmitic, palmitoleic and stearic acids from fruits grown in the southwestern region had a higher relative percentage, whereas fruits of the northern and eastern regions behaved similarly, except for the locality EG, in which values were similar to the



% C: Epidermis percentage. % P: Pulp percentage. T: Texture. L * a * b * C * H *: colorimetric vectors. VA: Apparent volume. DE: Equatorial diameter. DA: Bulk density. % PP: Weight loss percentage. % S: percentage of Seed percentage. DP: Polar diameter. DM: Days until ripening. P: Fruit weight.

Figure 1: Analysis of factors (A) and graph of discriminant functions (B) for physical variables associated with Hass avocado quality and its relationship with the evaluated localities.

Table 3: Multiple rank test for the physical variables associated with Hass avocado quality and its relationship with the evaluated localities

Variable	BV	IM	C S	EB	EC	EG	LA	LE	P-value
N (g/Kg)	9.3ab	6.6a	9.9b	8.3ab	8.2ab	9.4ab	9.5ab	7.3ab	0.0245
P (g/Kg)	1.3abc	0.8a	2.0d	1.5cd	1.1abc	1.4bc	1.1abc	0.8ab	0.0007
K (g/Kg)	13.0a	13.1a	16.9a	15.0a	14.5a	14.0a	16.1a	14.4a	0.2412
Ca (g/Kg)	1.9a	0.4a	0.3a	0.5a	0.4a	0.5a	0.6a	0.7a	0.4551
Mg (g/Kg)	0.9abc	0.7a	1.1bc	0.9abc	0.9abc	0.8ab	1.2c	1.1bc	0.0098
Na (g/Kg)	0.03a	0.03a	0.14a	0.03a	0.03a	0.03a	0.03a	0.03a	0.4934
S (g/Kg)	1.3a	1.2a	1.1a	1.3a	1.2a	1.5a	1.4a	1.0a	0.2589
Fe (mg/kg)	22.24a	15.00a	27.31a	18.91a	15.00a	17.37a	24.07a	18.58a	0.1487
Cu (mg/kg)	6.64c	3.00a	9.29d	5.36bc	3.00a	3.42ab	6.47c	3.99ab	0
Mn (mg/kg)	10.99a	3.37a	8.11a	19.43 a	3.40a	3.92a	5.92a	5.44a	0.054
Zn (mg/kg)	23.73c	10.21a	25.32c	20.54bc	13.31ab	21.48bc	21.21bc	13.45ab	0.0019
B (mg/kg)	11.73a	12.66a	79.35c	46.965bc	24.30ab	12.75a	20.46a	16.39a	0.0139
Vitamin E (g/Kg DB)	1.72a	2.1a	0.7a	1.6a	1.3a	1.1a	1.2a	0.7a	0.1516
Ashes (g/Kg)	115.8a	107.2a	131.2a	87.3a	106.3a	113.7a	110.9a	101.1a	0.3434
Ethereal extract (g/Kg)	622.1a	651.3a	627.6a	645.0a	647.4a	651.4a	610.8a	630.2a	0.116
Protein (g/Kg)	58.0a	42.7a	61.9a	52.0a	51.1a	56.3a	59.3a	45.6a	0.0585
Crude fiber (g/Kg)	270.2d	242.1cd	194.7a	211.1abc	207.7ab	209.4b	222.5abc	235.2bc	0.0003
Palmitic acid (%R)	18.14ab	25.34c	12.70a	13.71a	12.58a	20.46bc	15.76ab	15.84ab	0.0212
Palmitoleic acid (%R)	9.81d	12.85e	5.92ab	5.53ab	4.55a	9.65cd	7.62bcd	6.91abc	0.0022
Esteric acid (%R)	0.19cd	0.24d	0.10ab	0.13abc	0.16bc	0.09a	0.11ab	0.13abc	0.0067
Oleic acid (%R)	55.13ab	46.20a	68.46c	68.98c	71.20c	53.81ab	62.46bc	65.41bc	0.0218
Arachidonic acid (%R)	0.83 a	0.65a	0.74a	0.71 a	0.68a	0.80a	0.71a	0.63a	0.6347
Linoleic acid (%R)	5.91d	5.04cd	4.30abc	3.34ab	3.26a	4.77bcd	4.65abcd	3.71abc	0.0291
Linolenic acid (%R)	10.01 a	9.70a	7.79a	7.62 a	7.58a	10.45a	8.71a	7.38a	0.3016
Sum saturated (%R)	18.34ab	25.57c	12.81a	13.84 a	12.73a	20.55bc	15.87ab	15.97ab	0.0203
Sum mono-insaturated (%R)	64.93 a	59.05a	74.38a	74.51 a	75.75a	63.44a	70.08a	72.31a	0.0541
Sum poli-insaturated (%R)	12.39ab	11.51b	14.36ab	16.45ab	14.97ab	19.07b	13.19ab	9.58a	0.0302
Saturated / unsaturated acids	0.45cd	0.30a	0.33ab	0.43bcd	0.47d	0.35abc	0.37abcd	0.45cd	0.0012

DB = Percentage in dry base; %R = Relative percentage ones from the southwestern region. Regarding arachidonic and linolenic acids, as well as the sum of monounsaturated and polyunsaturated acids, there were no differences between locations (P > 0.05). For oleic acid, the fruits grown in the northern and eastern regions had significantly higher values (P < 0.05) compared to fruits grown in the eastern or southwestern regions. The sum of saturated acids showed a constant behavior between localities; however, the locality IM showed differences (P < 0.05) with values 30% higher than the other localities. In relation to the saturated/unsaturated acid ratio, there was no difference (P > 0.05) between most of the localities, with the exception of the locality IM, the northern fruits and the locality EC (Table 3).

In Figure 2A, the discrimination analysis shows a close relationship between the concentration of linolenic acid and the concentrations of nitrogen (N), zinc (Zn) and phosphorus (P), as well as a relationship between the concentration of polyunsaturated fatty acids (sum of polyunsaturated acids) and the concentrations of sulfur (S) in avocado fruits. The discriminant functions 1 and 2 showed Lambda-Wilks values of $1.2394*10^{-20}$ and $3.6213*10^{-7}$, respectively, indicating that with 95% confidence, these two functions have the ability to discriminate avocado fruits based on chemical variables and their origin (region). The variables with the highest discriminating power were the concentration of zinc (Zn), sulfur (S), magnesium (Mg), nitrogen (N), phosphorus (P), linoleic acid, linolenic acid, and palmitic acid, as well as saturated/unsaturated fatty acid ratio, the sum of polyunsaturated fatty acids and the sum of saturated fatty acids (Figure 2A).

On the other hand, the cluster formation by localities can be observed in Figure 2B. The fruits of localities EB and CS form a defined cluster, with similar chemical variable relationships between these localities. However, the separation of the other localities from their region is considered among these, which means that in chemical terms, the fruits from the southwestern and eastern regions are not similar among them.

DISCUSSION

Physical variables associated with Hass avocado quality and its relationship with the evaluated localities

In terms of variables associated with size and volume, it was found that plots planted at a higher elevation showed a better performance in terms of quality, with a higher percentage of extra quality. This must be a differentiating factor from the production systems cultivated under this environmental condition since yields can be compared to other regions where the elevation is lower. Additionally, the extra quality of fruits may be associated with the possible influence of differential management at the evaluated farms and the level of infestation of pests and pathologies such as the avocado wilt complex, which dramatically affects the quantity and quality produced (Torres-Jaimes *et al.*, 2015; Salazar-García *et al.*, 2016b; Ramírez-Gil *et al.*, 2017).

In the case of epidermis yield, the results found are comparable to those reported in some localities in Mexico, with values between 12.3-16.6% (Salazar-García *et al.*, 2016a), and with few variations compared to other regions in Colombia (Buelvas Salgado *et al.*, 2012). Regarding the percentages of epidermis, the lowest values were found at higher elevations, which indicates that avocado cv. Hass fruits tend to thicken their epidermis to reduce water loss in warmer climates with lower relative humidity conditions (lower elevation).

Pulp yields in all localities were higher to those reported in Jalisco, Michoacán, and Nayarit (Mexico) with values of 60.3, 59.2 and 58.7%, respectively (Salazar-García *et al.*, 2016b). In this sense, for growing areas in Colombia above 1,770 m.a.s.l, pulp content is higher than the international average (64-70%), whereas at lower elevations it decreases significantly to contents close to 63%. Based on these results, it can be inferred that fruit weight and pulp content decrease at a lower elevation.

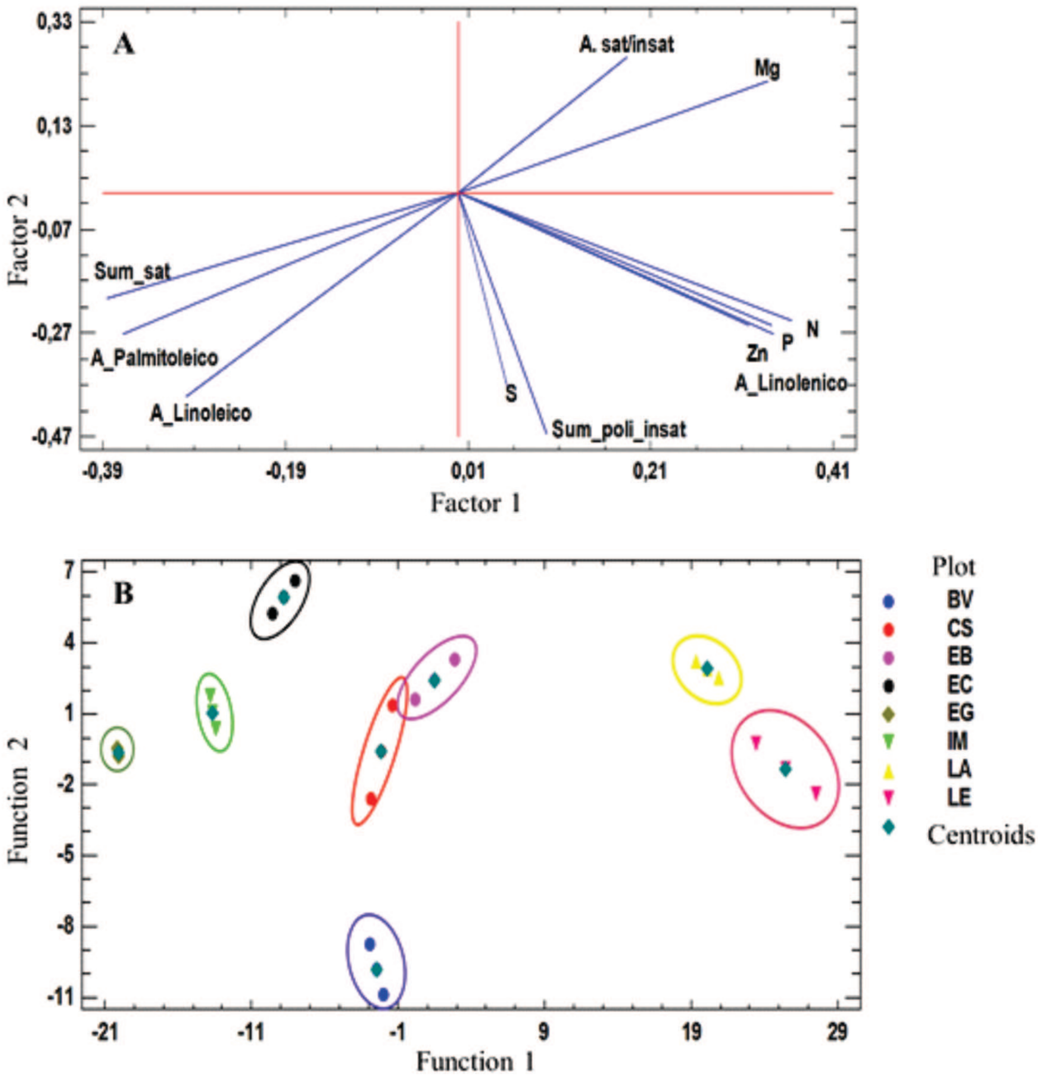
Regarding fruit color at harvest, this value was different among the studied localities, and apparently, it was not directly related to any other physical or climatic variable. This result confirms theories of diversity and ambiguity of harvest and postharvest variables in tropical fruits, a factor that is possibly affecting their final quality (Henao-Rojas & Rodríguez, 2016; Astudillo & Rodriguez, 2018).

The relationships between color, geometric variables, pulp and seed percentage, and weight loss during ripening were grouped into two functions with the ability to discriminate avocado fruits in relation to their location. These differences between regions can be due to environmental and edaphic conditions, among others (Salazar-García *et al.*, 2016b; Hernández *et al.*, 2016), and management or genetic characteristics of individuals (Hernández *et al.*, 2016; Ramírez-Gil *et al.*, 2017).

Chemical variables associated with Hass avocado quality and its relationship with the evaluated localities

Statistically different values (P < 0.05) in the concentration of chemical elements associated with avocado fruits from different growing areas indicate an important variability in terms of chemical fruit quality and nutritional values under preharvest management. In this sense, N concentration can affect the quality of fruits, since the assimilation of Ca^{2+} decreases in the presence of excessive amounts of this element. This reduces the postharvest storage of fruits, increases ripening heterogeneity (Hernández *et al.*, 2016; Hernández *et al.*, 2017), and plays an important role in the susceptibility to pathologies (Willingham *et al.*, 2006). In the same way, Ca^{2+} concentration and its relationships with other nutrients such as K^{++} and N have a significant effect on postharvest softening, and therefore, on fruit firmness, which is a primary factor for consumer preference (Witney *et al.*, 1990). Elements such as Mn^{+2} and Mg^{++} are usually important cofactors of enzymes for an adequate ripening and carbohydrate and lipid hydrolysis, which can confer certain attributes that can be highlighted in Colombian fruits.

The fatty acid profile found in avocado fruits was highly related to the biogeographic region where plots were located. This is the reason why it was selected as a biomarker to determine areas for the development of this fruit (Donetti & Terry, 2014; Ferreyra *et al.*, 2016; Tan *et al.*, 2017). Most of the studied localities exceeded the international standards in preharvest quality parameters of avocado fruits, with the exception of palmitic acid values, which showed values below the international reports (20-25%) in all plots (Donetti & Terry, 2014; Takenaga *et al.*, 2008; Tan *et al.*, 2017). The amount of fatty acids in avocado fruits, especially the unsaturated type, is important since these acids have been associated with a decrease in the risk of cardiovascular diseases,



Sat/unsat: saturated/unsaturated fatty acid ratio. Sum_sat: sum of saturated fatty acids. Sum_poli_unsat: Sum of polyunsaturated fatty acids. Palmitoleic_A: palmitoleic acid concentration. Linoleic_ A: linoleic acid concentration. Linolenic_ A: linolenic acid concentration. Mg: Magnesium concentration in fruit. N: Nitrogen concentration in fruit. P: Phosphorus concentration in fruit. Zn: concentration of Zinc in fruit. S: Sulfur concentration in fruit.

Figure 2: Analysis of factors (A) and graph of discriminant functions (B) for chemical quality variables associated with Hass avocado quality and its relationship with the evaluated localities.

weight control and hyperlipidemia treatment (Pérez-Méndez & García-Hernández, 2007; Rodriguez-Sanchez *et al.*, 2015; Monika & Geetha, 2015). In addition, these acids are determinants of quality and are especially related to taste.

As in the case of the findings for the physical variables, the chemical properties were grouped by localities. This is why it is necessary to know the soil and environmental factors and establish the agronomic practices that can favor desirable chemical factors in tropical climates such as the one observed in Colombia.

The results found in this work show two important aspects that must be taken into account by the Colombian avocado industry. The first aspect is associated with the physical, chemical and nutritional parameters. These parameters show that the fruit produced in the regions of Antioquia, Colombia have high-quality standards. This may be a factor of product differentiation that could be accessed through niche markets specialized in high-quality products, and by trying to improve other preharvest, harvest and postharvest features that determine fruit quality (Pedreschi *et al.*, 2016; Ferreyra *et al.*, 2016; Hernández *et al.*, 2016; Tan *et al.*, 2017). As a second factor of importance, it was possible to observe a marked differentiation in fruit quality under the edaphic, environmental and management conditions of the evaluated farms. This differentiation can be an alternative to improve the profitability of some productive systems, especially those located at heights above 2,300 m of elevation. In these areas, yields are lower but better quality standards are obtained compared to plots located at lower elevations. For this reason, production models could be developed with the denomination of “special avocados”.

The final fruit quality not only depends on preharvest factors such as those evaluated in this work since there are a series of interactions and management practices during the harvest and postharvest that can alter some fruit characteristics (Hernández *et al.*, 2016). Therefore, it is recommended to carry out the pertinent studies in order to determine better strategies to maintain fruit quality.

CONCLUSIONS

The physical, chemical and nutritional quality of avocado cv. Hass fruits grown in the tropics is similar or superior to that reported for other producing areas worldwide. In addition, statistical relationships between locality and quality can be observed.

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