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Study of environmental factors on the fat profile of Hass avocados

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ABSTRACT

Dry matter, fat content and fatty acid profiles were analysed in 31 Hass avocado samples from Tenerife collected in two areas and at two altitudes. Avocados have a higher dry matter and fat content towards the end of the production period. The main fatty acid presented was oleic acid, followed by palmitic acid. Oleic and gadoleic acids and MUFAs increased in avocados harvested between November and February. Avocados from the northern area presented higher contents of dry matter, fat, oleic and gadoleic acids and MUFAs than those produced in the southern area. Monounsaturated fatty acids were the most abundant FAs in both areas. In the northern area and orchards at middle altitudes avocados had higher fat and dry matter contents than orchards located at low altitudes, while the opposite occurred in the southern area. The influence of the production altitude on the percentage of oleic acid was different according to the area.

1. Introduction

The avocado (*Persea americana* Mill.) is a crop well adapted to subtropical areas such as the Canary Islands. Hass and Fuerte are the most cultivated varieties in the Canary Islands, with the first being predominant. In addition, the cultivated area on the islands increases every year, especially on the islands where its production is greater (La Palma, Tenerife and Gran Canaria) (INSTAC, 2022). Although most Hass production is marketed in the Canary Islands, it is expected that in the near future, appreciable quantities of this fruit will begin to be marketed on the European continent under a Protected Geographical Indication (PGI). (Gobierno de Canarias, 2023; ASGUACAN, 2020). Carvalho et al. (2015) indicated that the study of the fatty acid content in avocado is a variable to consider in futures studies for a protected designation of origin (PDO), as it shows a close relationship with the geographical growing area and its importance to human health.

Avocado is an oleaginous climacteric fruit with a well-known nutrient richness. It has relatively low percentages of water (65–75%) compared to other fruits. The percentage of fat is between 15% and 20% (approximately 60–70% of the dry pulp). The fat content increases after fruit ripening, while the water content decreases. The lipid fraction of avocado has a fatty acid profile similar to that of olive oil, since monounsaturated fatty acids predominate, especially oleic acid, over the rest of the fatty acids. In addition to oleic acid, the pulp also contains palmitic, linoleic and palmitoleic acids, with low levels of stearic acid. Thus, oleic acid represents 50–60% of the total fatty acids, followed by palmitic (15–20%), palmitoleic (6–10%), linoleic (11–15%) and linolenic (1%) acids (Donetti & Terry, 2014; Ferreyra et al., 2016; Jimenez et al., 2021; Ozdemir and Topuz, 2004).

The higher commercialization period of avocados in the Canary Islands is between the months of November and March, although it can last until June. In addition, the orography of the islands allows its cultivation from sea level to 500–600 m of altitude in the inner side of the islands and on two production areas, north and south, which have very different climates. It is important to understand the variation in dry matter, total fat and fatty acid profiles in relation to various environmental factors typical of these islands, specifically on the island of Tenerife, in order to establish which is the time, area and altitude that allows avocados of the highest quality to be obtained. This quality could be used as a commercial advantage over avocados imported from non-European countries, where avocados are produced in completely different periods, soil and climatic conditions to those found in the Canary Islands.

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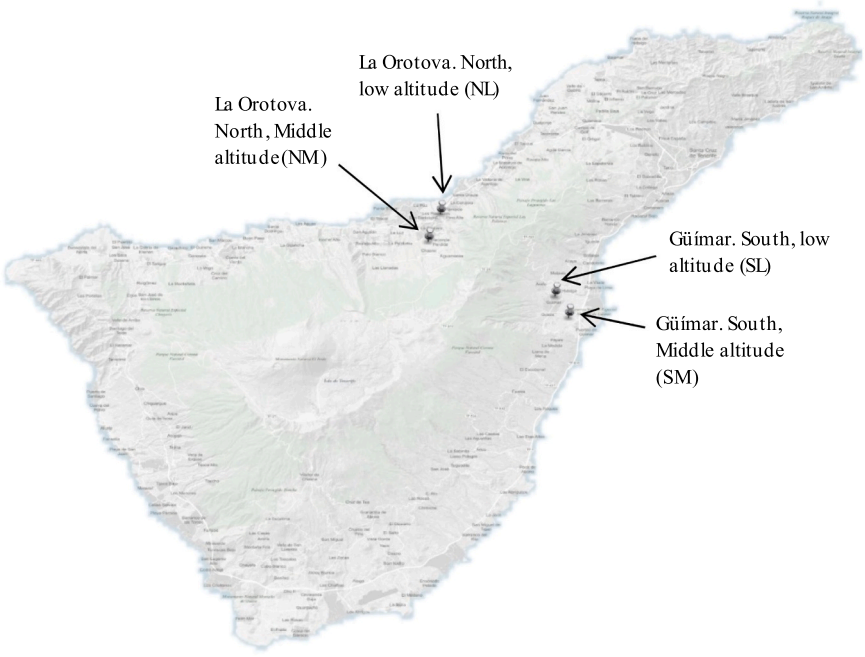

Fig. 1. Map of orchards in Tenerife Island.

Table 1
Climatic conditions of the orchards, considering 6 months prior to harvest.

Month of harvest	Region	RH (%)	Tmean (°C)	Tmax (°C)	Tmin (°C)	TPP* (mm)	TIR* (mm/ month)
November	North Low	81.2	20.4	23.9	17.3	89.4	541
	North Middle	77.3	20.5	24.8	17.2	109	521
	South Low	70.8	22.0	26.3	18.3	45.3	789
	South Middle	69.7	21.3	25.9	17.4	80.6	789
December	North Low	80.7	19.8	23.5	16.8	138	488
	North Middle	76.6	20.0	24.3	16.8	167	475
	South Low	70.4	21.3	25.7	17.8	77.9	721
	South Middle	69.5	20.6	25.2	16.8	105	721
January	North Low	79.2	18.9	22.9	15.8	193	441
	North Middle	75.0	19.2	23.6	16.0	244	430
	South Low	70.6	20.1	24.5	16.8	101	617
	South Middle	69.8	19.3	23.9	15.7	79.8	626
February	North Low	77.2	18.2	22.3	15.0	241	393
	North Middle	73.0	18.4	22.8	15.3	292	394
	South Low	70.8	19.1	23.2	15.7	112	532
	South Middle	71.1	18.0	22.2	14.6	126	532
Mean	North	77.5	19.4	23.5	16.3	184	460
	South	70.3	20.2	24.6	16.6	91	666

RH: Average relative humidity; Tmean: Average temperature; Tmax: maximum temperature; Tmin: minimum temperature; TPP: Total precipitation; TIR: Total irrigation requirements.
* These data correspond to the sum of the total precipitation and the sum of the irrigation requirements of each orchard.

2. Materials and methods

2.1. Samples

In Tenerife, there are two main production areas for cv. "Hass", Orotava and Güímar. Orotava is located north of the island, and Güímar is located south of the island. In each area, avocados were collected from two orchards located at two altitudes: "low" (Orotava at 129 m a.s.l., and Güímar at 148 m a.s.l.) and "middle" (Orotava at 483 m a.s.l., and Güímar at 300 m a.s.l.) (Fig. 1). Therefore, samples were named North Middle (NM), North Low (NL), South Middle (SM) and South Low (SL). These samples were collected in the months of maximum production and demand (November, December, January and February) beginning in November 2019 until February 2021, which results in a total of 8 months of sampling. Table 1 indicates the climatic conditions (RH = average relative humidity, Tmean = average temperature, Tmax = maximum temperature, T min = minimum temperature, TPP = total precipitation, and TIR = total irrigation requirements) of every orchard, considering 6 months prior to harvest (including harvest month) (Agrocabildo, 2022).

In all the farms sampled, the trees were over 20 years old, the plantation framework was 4 × 5 m, that is, 25 m^2 per tree, and the productive load of the trees that were sampled was very similar. Each sample consisted of 18 avocados from 5 different trees. A sample was taken every sampling month (8 months) in 4 orchards (two altitudes and two locations), except on January 21, when samples were only taken in 3 of the sampling orchards. A total of 31 samples were analysed. Avocados were green harvested and left to ripen in chambers at 20 °C with 95% RH (exogenous ethylene was not used) until reaching the same degree of ripening.

2.2. Analytical methods

Once ripe, 5 avocados were randomly taken from each sample, the seed and skin were removed, and the pulp was mixed and homogenized. Various aliquots were taken from this homogenate to carry out subsequent analyses. All analyses were performed in triplicate. Dry matter was determined by the gravimetric method until constant weight (AOAC et al., 2006). For the determination of the fat content, the Soxhlet

Table 2
Results (mean±standard deviation) of dry matter (%), fat (%), and fatty acid profile (% of total fatty acids) in the two locations per month.

Parameter	Area	November	December	January	February
Dry matter	North	**26.8 ± 3.48^{a}**	**28.8 ± 4.17^{ab}**	28.5 ± 3.23^{ab}	**31.4 ± 2.91^{b}**
	South	**21.8 ± 1.40^{a}**	**24.3 ± 2.73^{b}**	26.8 ± 2.38^{c}	**28.6 ± 1.61^{d}**
Fat	North	**59.1 ± 4.52^{a}**	**59.0 ± 2.71^{a}**	**60.9 ± 2.54^{a}**	**62.2 ± 3.39^{a}**
	South	**52.5 ± 2.67^{a}**	**53.9 ± 0.58^{a}**	**57.8 ± 2.59^{b}**	**57.1 ± 3.20^{b}**
Myristic (14:0)	North	**0.067 ± 0.01^{b}**	**0.062 ± 0.00^{b}**	**0.057 ± 0.01^{a}**	**0.062 ± 0.01^{b}**
	South	**0.082 ± 0.01^{b}**	**0.081 ± 0.01^{b}**	**0.069 ± 0.01^{a}**	**0.073 ± 0.01^{a}**
Palmitic (16:0)	North	22.7 ± 0.74^{b}	22.0 ± 0.86^{b}	**20.1 ± 0.99^{a}**	19.5 ± 1.58^{a}
	South	23.3 ± 1.11^{c}	22.5 ± 0.68^{b}	**21.6 ± 0.16^{b}**	20.3 ± 1.29^{a}
Margaric (17:0)	North	**0.036 ± 0.01^{a}**	**0.032 ± 0.01^{a}**	**0.033 ± 0.02^{a}**	**0.034 ± 0.01^{a}**
	South	**0.054 ± 0.01^{a}**	**0.056 ± 0.01^{a}**	**0.049 ± 0.01^{a}**	**0.046 ± 0.01^{a}**
Stearic (18:0)	North	**0.582 ± 0.04^{c}**	**0.564 ± 0.03^{bc}**	**0.547 ± 0.05^{ab}**	**0.525 ± 0.02^{a}**
	South	**0.677 ± 0.05^{c}**	**0.615 ± 0.03^{b}**	**0.606 ± 0.01^{b}**	**0.559 ± 0.04^{a}**
Arachidic (20:0)	North	**0.084 ± 0.00^{a}**	**0.080 ± 0.01^{a}**	**0.079 ± 0.01^{a}**	0.078 ± 0.01^{a}
	South	**0.098 ± 0.01^{b}**	**0.088 ± 0.00^{a}**	**0.088 ± 0.01^{a}**	0.085 ± 0.01^{a}
Palmitoleic (16:1)	North	12.4 ± 1.58^{b}	**11.8 ± 1.35^{b}**	**10.4 ± 1.18^{a}**	**10.3 ± 1.39^{a}**
	South	12.7 ± 0.37^{b}	**12.8 ± 0.47^{b}**	**11.6 ± 0.12^{a}**	**11.4 ± 0.58^{a}**
Cis-10-heptadecenoic (17:1)	North	0.097 ± 0.00^{a}	0.098 ± 0.00^{a}	0.098 ± 0.01^{a}	0.106 ± 0.01^{b}
	South	0.101 ± 0.01^{a}	0.102 ± 0.01^{a}	0.099 ± 0.01^{a}	0.098 ± 0.01^{a}
Oleic (18:1)	North	**50.9 ± 3.74^{a}**	**51.3 ± 3.48^{a}**	**55.1 ± 3.19^{b}**	**57.1 ± 4.10^{b}**
	South	**47.3 ± 1.03^{a}**	**47.0 ± 1.06^{a}**	**50.5 ± 0.19^{b}**	**52.3 ± 1.56^{c}**
Gadoleic (20:1)	North	0.171 ± 0.01^{a}	**0.176 ± 0.01^{a}**	**0.183 ± 0.01^{b}**	**0.194 ± 0.01^{c}**
	South	0.167 ± 0.01^{b}	**0.161 ± 0.01^{a}**	**0.170 ± 0.01^{b}**	**0.179 ± 0.01^{c}**
Linoleic (18:2)	North	**12.3 ± 1.54^{a}**	**13.2 ± 1.47^{a}**	**12.8 ± 1.67^{a}**	**11.6 ± 2.17^{a}**
	South	**14.8 ± 0.56^{b}**	**15.8 ± 0.70^{c}**	**14.3 ± 0.17^{a}**	**14.3 ± 0.58^{a}**
Linolenic (18:3)	North	**0.724 ± 0.06^{ab}**	**0.792 ± 0.08^{b}**	**0.793 ± 0.09^{b}**	**0.655 ± 0.13^{a}**
	South	**0.929 ± 0.10^{b}**	**1.03 ± 0.08^{c}**	**0.887 ± 0.03^{ab}**	**0.833 ± 0.09^{a}**
Total SFA	North	23.5 ± 0.75^{b}	22.7 ± 0.85^{b}	**20.8 ± 0.99^{a}**	20.2 ± 1.59^{a}
	South	24.2 ± 1.11^{d}	23.3 ± 0.67^{c}	**22.5 ± 0.16^{b}**	21.0 ± 1.32^{a}
Total MUFA	North	**63.6 ± 2.20^{a}**	**63.4 ± 2.15^{a}**	**65.7 ± 2.01^{b}**	**67.7 ± 3.08^{c}**
	South	**60.2 ± 0.78^{a}**	**60.1 ± 0.70^{a}**	**62.4 ± 0.26^{b}**	**64.0 ± 1.27^{c}**
Total PUFA	North	**13.1 ± 1.60^{a}**	**14.0 ± 1.52^{a}**	**13.6 ± 1.75^{a}**	**12.2 ± 2.30^{a}**
	South	**15.8 ± 0.65^{b}**	**16.8 ± 0.65^{c}**	**15.2 ± 0.19^{a}**	**15.1 ± 0.65^{a}**

Lines with different letters indicate that there are significant differences ($P < 0.05$) according to Duncan's test.
Highlighted in bold when there were significant differences ($P < 0.05$) between the two locations, considering each month independently.
SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

method was applied using n-hexane as the extracting agent. After eliminating the excess n-hexane, the amount of fat contained in the sample was calculated by gravimetry, expressing the result in dry weight (Meyer and Terry, 2008).

To analyse the fatty acid profile (FAME), fat extraction was performed according to the method of Folch et al. (1957). Five hundred milligrams of the homogenate was mixed by shaking strongly with 10 ml of chloroform:methanol (2:1, v/v) (Christie, 2003) and 2.5 ml of potassium chloride (KCl; 0.88% w/v). After centrifugation of the mixture at 1500 rpm for 5 min, the lower fraction containing the dissolved lipids was recovered, and the organic solvent was completely evaporated under a nitrogen atmosphere. This residue was redissolved in chloroform:methanol (2:1, v/v) at a concentration of 10 mg/ml, 0.01% butylhydroxytoluene (BHT) was added as an antioxidant in the presence of nitrogen, and the residue was stored at − 20 °C until analysis. Individual fatty acids were determined by gas chromatography with a flame ionization detector after derivatization by acid transmethylation of 1 mg of lipid to which 5% nonadecanoic acid (C19:0) was added as an internal standard. FAMEs were quantified using a TRACE-GC Ultra gas chromatograph (Thermo Fisher Scientific Inc., Waltham, Massachusetts, USA) equipped with an on-column injector, a flame ionization detector and a fused silica capillary column, Supelcowax TM 10 (30 m × 0.32 mm I.D. x 0.25 μm; Sigma—Aldrich Co., St. Louis, Missouri, USA). Helium was used as the carrier gas. The injector temperature was 50 °C, and the detector temperature was 240 °C. The oven temperature was programmed between 50 and 230 °C, with a heating rate of 2 °C/min and 90 min of run. The fatty acids were identified and quantified by comparison between the sample and a reference standard (Oil Reference Standard AOCS, Sigma, St. Louis, MO, USA). The fatty acid composition was expressed as a percentage of total fatty acids.

2.3. Statistical analyses

Statistical analysis of the data was performed using the SPSS 25.0 program (Statistical Package for the Social Sciences Inc., Chicago, USA) for Windows. An analysis of variance (ANOVA), Duncan's test, and multivariate analysis of variance (MANOVA) were applied to the quantitative variables considering different qualitative variables such as harvest month, area and altitude of the orchards. Significant differences were confirmed when the level of significance was lower than 0.05. Pearson's correlation study was also performed. In addition, linear discriminant analysis (LDA) was applied to classify the avocado samples into homogeneous groups established according to the previous qualitative variables.

3. Results and discussion

3.1. Influence of the harvest season

The contents of dry matter and fat and the fatty acid profile (in percentage with respect to total fatty acids) in the two locations per harvest month are shown in Table 2. Dry matter increased significantly in the two production areas. In the north, dry matter increased from 26.8% in November to 31.4% in February, with significant differences between months. In the south, the increase was from 21.8% to 28.6% for the same period. Avocados harvested in February, which is the month nearing the end of the peak production period, had lower moisture levels than those harvested in November, when harvest begins. The fat content presented a similar behavior; that is, as the harvest season progressed, there was an increase in the fat content, with significant differences only in avocados from the south. This agrees with Donetti and Terry (2014) and Ozdemir and Topuz (2004).

The main fatty acid was oleic acid (47.0–57.1%), followed by palmitic (19.5–23.3%), linoleic (11.6–15.8%), and palmitoleic (10.3–12.8%), linolenic (0.66–1.03%), and stearic acids (0.53–0.68%). This fatty acid profile in avocados was similar to that detected by other

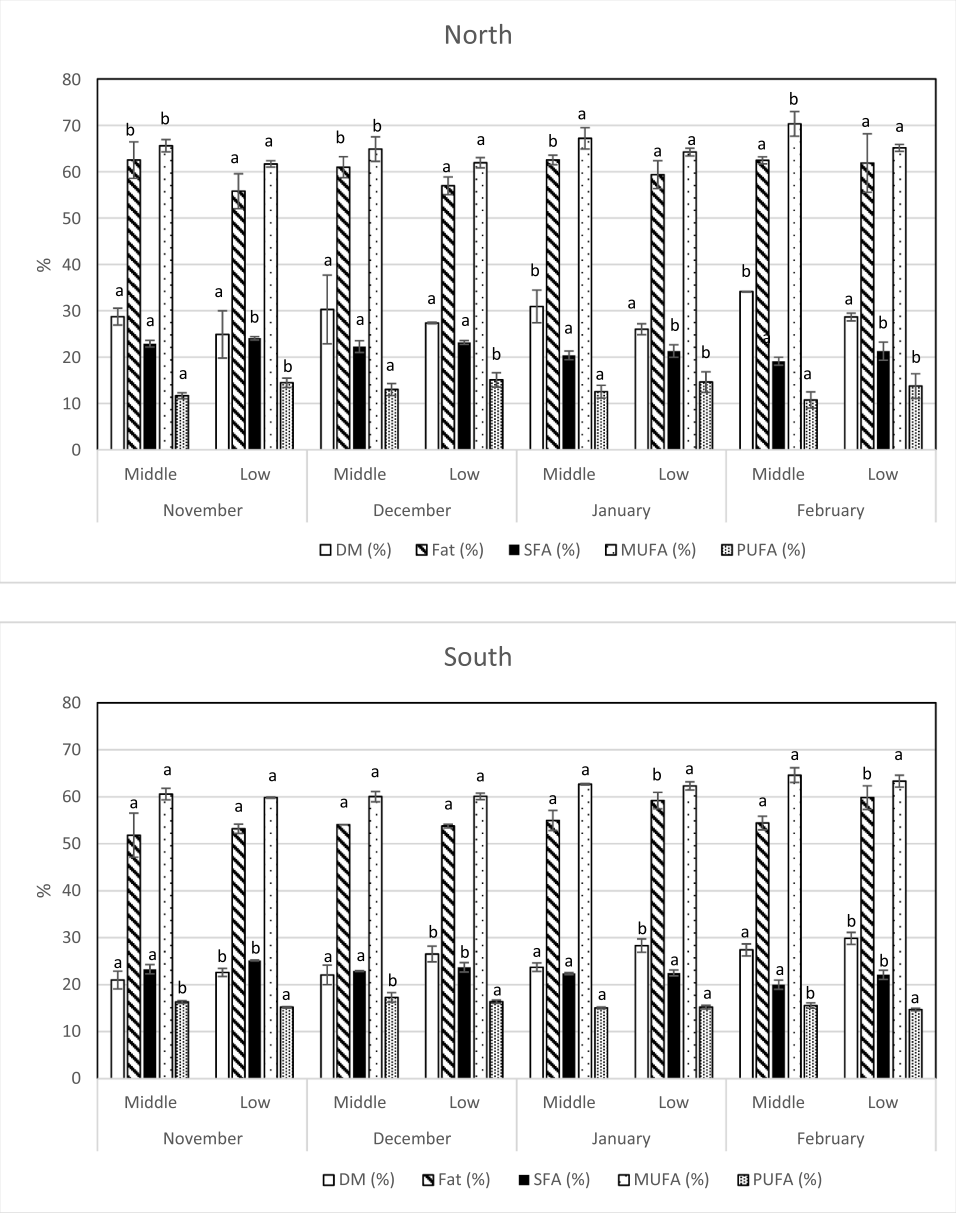

Fig. 2. Dry matter and fat (g/100 g), and SFA, MUFA, PUFA (in percentage with respect to the total fatty acids) differentiating between the 4 months of study and at the two altitudes, for the northern zone and the southern zone. For the same parameter and the same month, different letters indicate that there are significant differences ($p < 0.05$) depending on the altitude of the avocado production orchard.

researchers (Carvalho et al., 2015; Donetti and Terry, 2014; Henao-Rojas et al., 2019; Meyer and Terry, 2008; Ozdemir and Topuz, 2004; Villa-Rodríguez et al., 2011). In accordance with previous literature (Carvalho et al., 2015; Ozdemir and Topuz, 2004; Pedreschi et al., 2016; Villa-Rodríguez et al., 2011), other minor FAs were found, such as gadoleic (0.16–0.19%), cis-10-heptadecenoic (0.10–0.11%), arachidic (0.078–0.098%), myristic (0.057–0.082%) and margaric acids (0.032–0.054%).

Significant differences were found for the fatty acids analysed according to the harvest season and in the two production areas, with the exception of linoleic and arachidic acids from the North, cis-10-heptadecenoic in the South, and margaric acid in both zones (Table 2). In general, the percentages of these fatty acids decreased in harvested avocados between November and February. Thus, palmitic acid went from 22% of the total fat to approximately 20% in both locations. Oleic and gadoleic acids were an exception, as they increased; in the case of oleic acid, the increase was from 50.7% to 57.1% from November to February in the North and from 47.3% to 52.3% in the same period in the South. The oleic acid content increased while the palmitic acid content decreased when the average temperature and relative humidity decreased and total precipitation increased (Tables 1 and 2). Ozdemir and Topuz (2004) also observed that the contents of palmitic, palmitoleic, linoleic and arachidic acids decreased significantly from November to January, and only oleic acid increased. According to other investigations (Donetti and Terry, 2014; Ferreyra et al., 2016; Henao-Rojas et al., 2019), a higher average temperature in the month of production causes a lower content of oleic acid and a higher content of the remaining fatty acids. Ferreyra et al. (2016) found the maximum mean annual temperature to be the most important variable affecting the concentrations of oleic, palmitic, and palmitoleic acids.

If the fatty acids are grouped as saturated (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) (Table 2), it is observed how unsaturated fatty acids predominate in the two zones, with the percentages of SFA being less than 25% with respect to the total of fatty acids. MUFAs

Table 3
Results (mean±standard deviation) of dry matter (%), fat (%), and fatty acid profile (% of total fatty acids) in the two locations and two altitude per month.

Parameter	Area and altitude	November	December	January	February
Dry matter	NL	24.9 ± 5.10	27.4 ± 0.15	26.0 ± 1.19	28.6 ± 0.83
	NM	28.7 ± 1.81	30.3 ± 7.42	30.9 ± 3.52	34.1 ± 0.09
	SL	22.6 ± 0.87	26.5 ± 1.67	28.3 ± 0.91	29.9 ± 1.27
	SM	21.0 ± 1.89	22.1 ± 2.07	23.7	27.4 ± 1.28
Fat	NL	55.8 ± 3.8	57.0 ± 1.9	59.4 ± 3.0	61.9 ± 6.3
	NM	62.5 ± 3.9	61.0 ± 2.3	62.5 ± 1.0	62.4 ± 0.8
	SL	53.2 ± 1.0	53.8 ± 0.4	59.2 ± 2.1	59.8 ± 2.5
	SM	51.8 ± 4.7	54.1 ± 0.0	54.9	54.4 ± 1.5
Myristic (14:0)	NL	0.069 ± 0.01	0.064 ± 0.01	0.061 ± 0.01	0.069 ± 0.01
	NM	0.064 ± 0.01	0.061 ± 0.01	0.053 ± 0.01	0.056 ± 0.01
	SL	0.074 ± 0.01	0.080 ± 0.01	0.074 ± 0.01	0.071 ± 0.01
	SM	0.091 ± 0.01	0.082 ± 0.01	0.058	0.074 ± 0.01
Palmitic (16:0)	NL	23.3 ± 0.3	22.4 ± 0.4	20.6 ± 1.3	20.5 ± 2.0
	NM	22.1 ± 0.7	21.5 ± 1.3	19.6 ± 1.0	18.4 ± 0.9
	SL	24.3 ± 0.1	22.8 ± 1.0	21.7 ± 0.2	21.3 ± 1.0
	SM	22.4 ± 1.0	22.1 ± 0.1	21.6	19.2 ± 0.9
Margaric (17:0)	NL	0.045 ± 0.01	0.035 ± 0.01	0.037 ± 0.02	0.040 ± 0.01
	NM	0.027 ± 0.01	0.029 ± 0.01	0.029 ± 0.01	0.029 ± 0.01
	SL	0.053 ± 0.01	0.056 ± 0.01	0.050 ± 0.01	0.040 ± 0.01
	SM	0.056 ± 0.01	0.056 ± 0.01	0.048	0.053 ± 0.01
Stearic (18:0)	NL	0.57 ± 0.05	0.56 ± 0.04	0.53 ± 0.08	0.54 ± 0.01
	NM	0.60 ± 0.01	0.57 ± 0.02	0.56 ± 0.05	0.52 ± 0.01
	SL	0.68 ± 0.03	0.63 ± 0.03	0.61 ± 0.02	0.57 ± 0.02
	SM	0.68 ± 0.02	0.60 ± 0.03	0.61	0.54 ± 0.06
Arachidic (20:0)	NL	0.083 ± 0.01	0.078 ± 0.01	0.075 ± 0.01	0.085 ± 0.01
	NM	0.085 ± 0.01	0.082 ± 0.01	0.082 ± 0.01	0.071 ± 0.01
	SL	0.095 ± 0.01	0.085 ± 0.01	0.090 ± 0.01	0.090 ± 0.01
	SM	0.101 ± 0.01	0.090 ± 0.01	0.085	0.080 ± 0.01
Palmitoleic (16:1)	NL	13.8 ± 1.2	12.7 ± 0.5	11.3 ± 0.4	11.4 ± 1.5
	NM	11.1 ± 0.6	10.8 ± 1.6	9.4 ± 1.2	9.21 ± 0.1
	SL	12.7 ± 0.4	13.0 ± 0.7	11.6 ± 0.2	11.8 ± 0.5
	SM	12.6 ± 0.5	12.6 ± 0.3	11.7	11.0 ± 0.5
Cis-10-heptadecenoic (17:1)	NL	0.096 ± 0.01	0.098 ± 0.01	0.101 ± 0.01	0.109 ± 0.01
	NM	0.098 ± 0.01	0.098 ± 0.01	0.095 ± 0.01	0.103 ± 0.01
	SL	0.092 ± 0.01	0.098 ± 0.01	0.090 ± 0.01	0.093 ± 0.01
	SM	0.110 ± 0.01	0.106 ± 0.01	0.117	0.104 ± 0.01
Oleic (18:1)	NL	47.6 ± 1.9	48.9 ± 1.6	52.6 ± 1.3	53.4 ± 0.8
	NM	54.3 ± 1.9	53.8 ± 4.3	57.5 ± 3.5	60.8 ± 2.5
	SL	46.9 ± 0.3	46.8 ± 1.3	50.5 ± 0.0	51.2 ± 1.8
	SM	47.7 ± 1.8	47.2 ± 1.4	50.7	53.3 ± 1.1
Gadoleic (20:1)	NL	0.17 ± 0.01	0.18 ± 0.01	0.18 ± 0.00	0.19 ± 0.01
	NM	0.17 ± 0.01	0.17 ± 0.02	0.18 ± 0.01	0.20 ± 0.01
	SL	0.16 ± 0.01	0.16 ± 0.00	0.17 ± 0.01	0.17 ± 0.01
	SM	0.17 ± 0.01	0.16 ± 0.00	0.17	0.18 ± 0.01
Linoleic (18:2)	NL	13.7 ± 1.0	14.2 ± 1.5	13.8 ± 2.1	13.0 ± 2.5
	NM	11.0 ± 0.6	12.3 ± 1.3	11.8 ± 1.4	10.2 ± 1.6
	SL	14.4 ± 0.2	15.4 ± 0.3	14.3 ± 0.1	13.9 ± 0.3
	SM	15.3 ± 0.3	16.2 ± 1.0	14.2	14.7 ± 0.5
Linolenic (18:3)	NL	0.78 ± 0.01	0.85 ± 0.04	0.86 ± 0.08	0.75 ± 0.14
	NM	0.67 ± 0.01	0.73 ± 0.04	0.73 ± 0.02	0.56 ± 0.11
	SL	0.84 ± 0.04	0.97 ± 0.05	0.89 ± 0.05	0.77 ± 0.04
	SM	1.02 ± 0.03	1.08 ± 0.03	0.89	0.90 ± 0.07
Total SFA	NL	24.1 ± 0.4	23.2 ± 0.4	21.3 ± 1.3	21.3 ± 2.0
	NM	22.9 ± 0.7	22.3 ± 1.3	20.4 ± 0.9	19.1 ± 0.9
	SL	25.1 ± 0.1	23.7 ± 1.0	22.5 ± 0.2	22.1 ± 1.0
	SM	23.3 ± 1.0	22.9 ± 0.1	22.4	20.0 ± 1.0
Total MUFA	NL	61.7 ± 0.7	61.9 ± 1.1	64.2 ± 0.8	65.1 ± 0.7
	NM	65.6 ± 1.3	64.9 ± 2.6	67.2 ± 2.3	70.3 ± 2.7
	SL	59.8 ± 0.1	60.1 ± 0.7	62.3 ± 0.2	63.3 ± 1.3
	SM	60.6 ± 1.2	60.0 ± 1.1	62.7	64.6 ± 1.6
Total PUFA	NL	14.5 ± 1.0	15.1 ± 1.5	14.6 ± 2.2	13.8 ± 2.7
	NM	11.7 ± 0.6	13.0 ± 1.3	12.5 ± 1.4	10.7 ± 1.8
	SL	15.2 ± 0.2	16.4 ± 0.4	15.2 ± 0.2	14.7 ± 0.3
	SM	16.3 ± 0.3	17.3 ± 1.0	15.1	15.6 ± 0.6

NL: North low altitude; NM: North middle altitude; SL: South low altitude; SM: South middle altitude.
SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: poly-unsaturated fatty acids.

were the major, with average values of 65.1% and 61.6% for the southern and northern zones, respectively. Regarding the variation with the harvesting time, it is observed how the percentages of SFA and PUFA (only south) decrease significantly from the beginning of the collection season (November). However, the behaviour of the MUFAs was completely different, with higher percentages detected at the end of the harvest season (February) than at the beginning (November and December) or mid-season (January). Donetti and Terry (2014) indicated that the differences between growing areas in the oil composition could be a consequence of the different climatic conditions, soil composition and growing practices of the areas where fruit were grown.

Table 4
Multivariate analysis of variance (MANOVA).

	Month	Area	Altitude	Month x Altitude	Month x Area	Area x altitude	Month x Area x altitude
Dry matter	0.008	0.002	0.625	0.846	0.757	0.002	0.917
Fat	0.051	0.000	0.658	0.298	0.839	0.009	0.883
Myristic (14:0)	0.001	0.000	0.122	0.024	0.265	0.023	0.050
Palmitic (16:0)	0.000	0.028	0.002	0.419	0.756	0.912	0.894
Margaric (17:0)	0.662	0.023	0.267	0.742	0.577	0.051	0.581
Stearic (18:0)	0.003	0.001	0.940	0.671	0.438	0.358	0.981
Arachidic (20:0)	0.009	0.000	0.802	0.016	0.448	0.777	0.425
Total SFA	0.000	0.016	0.003	0.405	0.770	0.919	0.905
Palmitoleic (16:1)	0.002	0.009	0.001	0.894	0.632	0.007	0.856
Cis-10-heptadecenoic (17:1)	0.745	0.538	0.005	0.462	0.115	0.001	0.313
Oleic (18:1)	0.000	0.000	0.000	0.676	0.948	0.003	0.985
Gadoleic (20:1)	0.002	0.002	0.833	0.439	0.481	0.680	0.943
Total MUFA	0.000	0.000	0.001	0.617	0.986	0.009	0.978
Linoleic (18:2)	0.118	0.000	0.064	0.977	0.784	0.005	0.883
Linolenic (18:3)	0.001	0.000	0.542	0.487	0.222	0.000	0.544
Total PUFA	0.091	0.000	0.069	0.973	0.756	0.004	0.867

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

3.2. Influence of the harvesting area

Regarding the influence of the harvesting area (Table 2), avocados from the North showed significantly higher contents of dry matter and fat (28.9% dry matter and 60.3% fat) than those from the South (25.4% dry matter and 55.3% fat). In general, the percentages of fatty acids (myristic, palmitoleic, margaric, stearic, linoleic, linolenic, arachidic and gadoleic acids) in avocados from the North were lower ($P < 0.05$) than those from the South, while oleic acid and, therefore, the percentage of MUFAs showed an opposite trend. Avocados from the North showed higher percentages of oleic acid and MUFAs (53.6% and 65.1% respectively) than those from the South (49.3% and 61.7% respectively). The climatic data obtained in the southern area were different from those of the northern area in such a way that they had lower average relative humidity (70.3% in the south and 77.5% in the north), higher maximum temperature (24.6ºC in the south and 23.5ºC in the north), lower total precipitation (91 mm in the south and 184 mm in the north) and higher irrigation requirements (666 mm/month in the south and 460 mm/month in the north) (Agrocabildo, 2022). Henao-Rojas et al. (2019) also found, for oleic acid, that fruits grown in the northern and eastern regions of Antioquia (Colombia) had higher values ($P < 0.05$) than fruits grown in the eastern or southwestern regions. These same authors found differences ($P < 0.05$) in the percentages of fatty acids between localities (North, Southwest and East), with the exception of arachidonic and linolenic acids, as well as MUFAs and PUFAs. Landahl et al. (2009) found that the profile of fatty acids, fat and dry matter contents in 'Hass' avocados varied significantly according to origin (in a study on avocados from Spain, Chile and Peru), and Donetti and Terry (2014) determined that the fat composition differed according to origin (Spain, Chile and Peru) and harvest time (February to August).

3.3. Influence of the altitude of the orchard

Considering the northern region, the concentrations of dry matter and fat were higher in avocados from orchards located at mid-altitude compared to those at lower altitude (Fig. 2). The fatty acids most influenced by the altitude of the orchards were palmitoleic, oleic, linoleic and linolenic acids (Table 3). Oleic acid was the only fatty acid that showed a higher percentage in avocados produced at the middle altitude (53.8–60.8%) than at the low altitude (47.6–53.4%), and the same was true when MUFAs were considered. Avocados harvested at low altitudes showed significantly higher percentages of SFAs and PUFAs. In all cases, the differences were significant ($P < 0.05$), except for SFA in avocados harvested in December. Carvalho et al. (2015) showed that orchard altitude significantly affected the fatty acid metabolism of avocado fruits. They observed that the percentage of oleic acid was higher at higher altitudes (>1900 m a.s.l.), while the percentages of the rest of the fatty acids were higher when the altitudes of the orchards were lower.

In the case of avocados harvested in the southern area, the influence of altitude was different from those located in the north (Fig. 2). Dry matter and fat contents were higher in avocados harvested at low altitudes, with significant differences ($P < 0.05$) for the 4 months in dry matter and for the months of January and February in fat. With respect to the percentage of fatty acids, a different behaviour was also observed with respect to avocados harvested in the north. Those produced at the middle altitude showed higher contents of almost all the fatty acids analysed, except for palmitic acid (Table 3). No significant differences were detected in the percentage of stearic acid depending on the harvest altitude, and the influence for oleic acid was scarce, only detecting that those harvested at mid-altitude in February presented higher percentages ($P < 0.05$) of this fatty acid When SFAs, MUFAs and PUFAs were considered, PUFAs were present in a higher percentage at middle altitudes (except in January), while SFAs showed higher contents at low altitudes (except in January). The percentage of MUFAs was not affected by the altitude of production.

3.4. Statistical analysis

Interactions between the variables month x zone and month x zone x altitude were not significant for any of the quantitative variables analysed (Table 4). However, the interaction between the zone x altitude variables was important, since it was significant for the variables dry matter, fat, and myristic, palmitoleic, cis-10-heptadecenoic C17:1, oleic, linoleic, linolenic, MUFA and PUFA acids, while the interaction month x altitude was only significant for myristic and arachidic acids.

A large number of significant correlations ($P < 0.01$) were obtained between the variables studied (Table S1). The C17:1 acid and average RH were the only ones that did not show significant correlations with any other variable.

Dry matter, fat, and oleic and gadoleic acids were positively correlated with the total precipitation and negatively correlated with the rest of the climatological variables (Tmean, Tmax, Tmin, total irrigation requirements), while for the rest of the fatty acids, the behavior was the opposite. Due to their high correlation coefficients and level of significance ($P < 0.001$), the following correlations can be highlighted: total irrigation requirements vs dry matter (-0.798), fat ($r = -0.844$) and stearic acid (0.928), TPP vs oleic acid ($r = 0.854$) and palmitic acid ($r = -0.812$) (Fig. 3A), Tmean vs palmitic acid ($r = 0.874$) (Fig. 3B), Tmax vs stearic acid ($r = 0.920$) (Fig. 3C).

Oleic acid was negatively correlated with all fatty acids (except gadoleic acid) and therefore with SFAs and PUFAs and positively correlated with dry matter and fat. Carvalho et al. (2015) showed a high

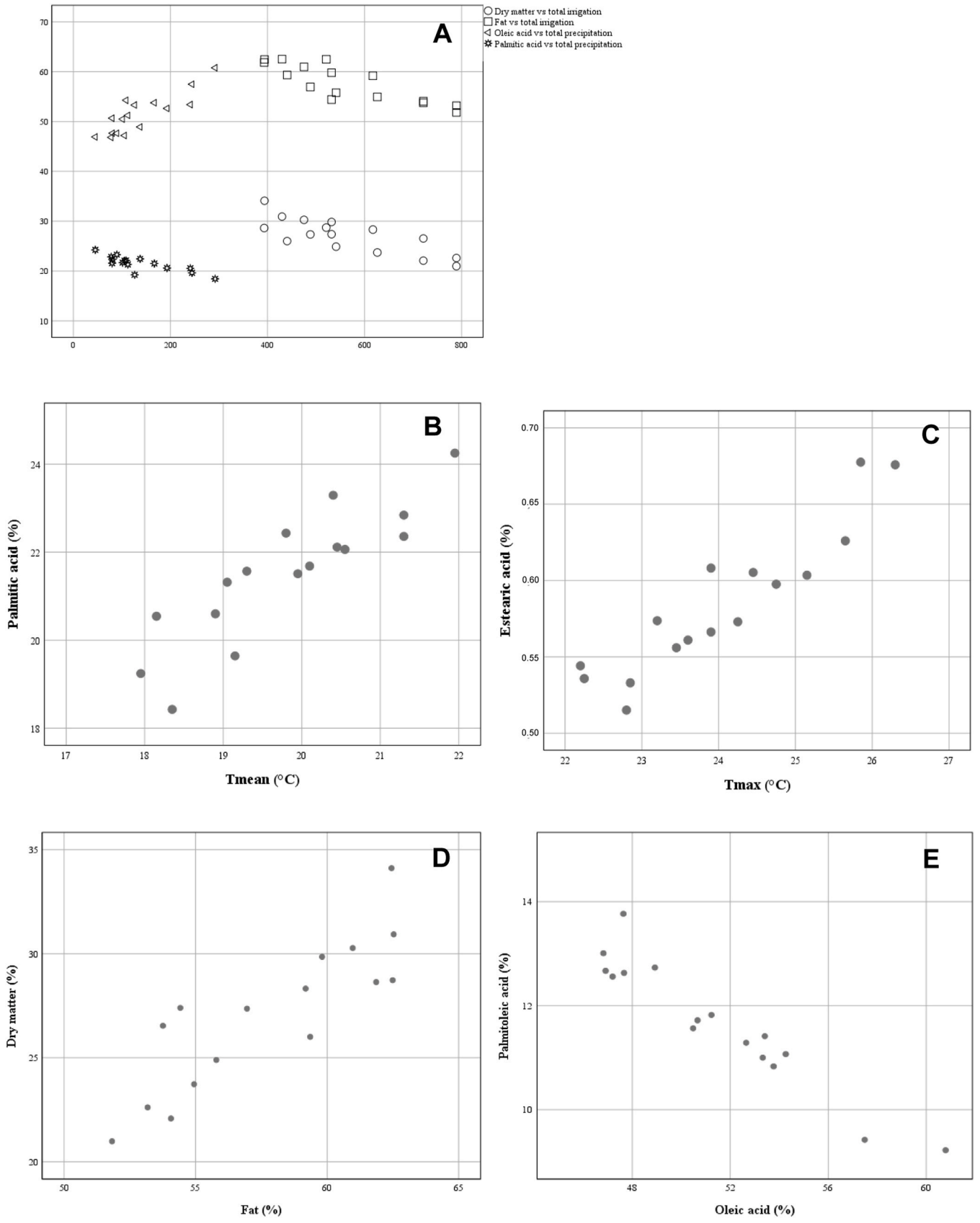

Fig. 3. Correlations between dry matter and fat with total precipitation, between oleic and palmitic acids with total irrigation requirements (A), between Tmean with palmitic acid (B), between Tmax with stearic acid (C); between fat and dry matter (D), and between oleic and palmitoleic acids (E).

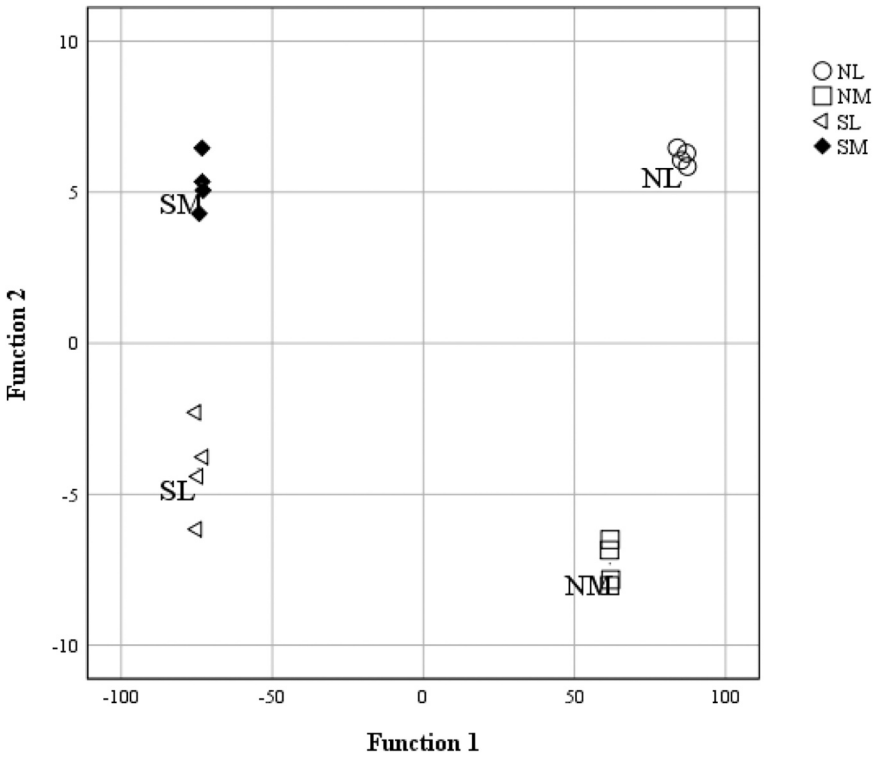

Fig. 4. Scatter diagram on the axes representing the two discriminant functions differentiating the avocado samples according to the area and altitude. NL = North low; NM = North middle; SL = South low; SM = South middle.

correlation coefficient between oleic acid (positive) and palmitic acid (negative) with dry matter. The following correlations can be highlighted: dry matter vs fat (r = 0.855) (Fig. 3D) and oleic acid (r = 0.836); palmitic acid vs palmitoleic acid (r = 0.853) and oleic acid (r = −0.862); oleic acid vs palmitoleic acid (r = - 0.955) (Fig. 3E) and linoleic acid (r = −0.861); and linoleic acid vs linolenic acid (r = 0.950). The high correlation between fat and dry matter could be used to predict fat content based on dry matter. Carvalho et al. (2015) also found a correlation between the percentages of fat and dry matter, and they indicated that this correlation could be used as a maturity index.

A stepwise LDA was performed to differentiate the avocado samples according to the region and altitude of production (Fig. 4); 88.2% (83.9% after cross-validation) of the avocado samples were correctly classified. The variables selected were margaric, stearic, palmitoleic, cis-10-heptadecenoic, linolenic and gadoleic acids and PUFAs. Therefore, a clear tendency was observed to differentiate the avocados produced in the north with respect to the southern region. It was also possible to differentiate those from the north based on their altitude where the orchard was located, while in the southern region, this differentiation was not appreciated. When other qualitative variables (zone, altitude or month) were introduced in the stepwise LDA, the percentages of well-classified samples within their group did not improve compared to the previous analysis.

4. Conclusions

The concentrations of dry matter, total fat and fatty acids of "Hass" avocados were influenced by the month, area and altitude of production. Avocados had higher dry matter, fat, oleic acid and MUFA contents towards the end of the production period, and they were also higher in avocados produced in the northern zone than in those produced in the southern zone. In general, the percentages of other fatty acids, SFAs and PUFAs decreased from November to February and were lower in those produced in the northern zone than in those produced in the southern zone. Altitude influenced the contents of dry matter, fat and fatty acids, and this variation was different depending on the area of the island where the avocados were harvested.

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CRediT authorship contribution statement

Clemente Méndez Hernández: Investigation. **Domingo Ríos Mesa**: Writing. **Beatriz Rodríguez-Galdón**: Investigation, Writing – review & editing. **Elena M. Rodríguez-Rodríguez**: Investigation, Writing – review & editing, Project administration.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. Elena Maria Rodriguez Rodriguez reports equipment, drugs, or supplies was provided by Tenerife Council.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2023.105544.

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