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Effect of Different Extraction Methods on Fatty Acids, Volatile Compounds, and Physical and Chemical Properties of Avocado (*Persea americana* Mill.) Oil

ALICIA ORTIZ MORENO,*,† LIDIA DORANTES,† JUVENCIO GALÍNDEZ,† AND ROSA I. GUZMÁN§

Department of Biochemical Engineering, Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, México City, Mexico, and Violetas 203 La Florida Satélite, Estado de México C.P. 53160, Mexico

Because Mexico is the number one producer of avocados in the world, this fruit has potential as a source for oil extraction. It is appropriate to further investigate the detailed changes that the oil undergoes when different extraction methods are applied. This research paper presents the study of the physical and chemical changes, the fatty acids profile, the trans fatty acid content, and the identification of volatile compounds of the oils from avocado pulp (*Persea americana* Mill.), obtained by four different extraction methods. The method with the greatest extraction yield was the combined microwave−hexane method. The amount of trans fatty acids produced in the microwave−squeezing treatment was <0.5 g/100 g. On the other hand, the amounts of trans fatty acids produced with the hexane and acetone treatments were 0.52 and 0.87 g/100 g, respectively. The method that caused the slightest modification to the oil quality was a novel combined extraction method of microwave−squeezing proposed by the authors.

KEYWORDS: Avocado; extraction; fatty acids; oil; *Persea americana* Mill.; trans configuration

INTRODUCTION

During recent years, significant public interest was generated by research on the effects of the consumption of different kinds of fats and their relationship to obesity, cardiovascular disease, and some types of breast and colon cancer (*1*, *2*).

The stereochemical cis or trans configuration of the edible oils and fats has been the subject of great concern. In nature, the majority of unsaturated fatty acids are cis isomers. The only trans fatty acids found in nature are the ones produced by bacteria in the gut of bovines, passing on to the meat, milk, and milk derivatives. Trans isomers are artificially produced during the industrial hydrogenation of edible oils. The processors make the liquid oils react with hydrogen to stabilize them, generating a stereochemical transformation at this point (*3*).

Trans fatty acids pose some negative effects on human metabolism, such as the inhibition of the unstauration and enlargement of the linoleic and linolenic acids in order to form other long-chain fatty acids of importance to the organism (*4*). They also produce a negative effect on the lipoproteins of human plasma, when increasing the low-density lipoproteins and decreasing the high-density lipoproteins, contributing to a higher incidence of cardiovascular disease (*3*, *5*−*7*). These effects, among others, could be why the U.S. Food and Drug Administration (FDA) published a law proposal (*8*) establishing that every food should declare the amount of trans fatty acids they contain, together with the recommendation that such an amount should not be >0.5 g/100 g of food.

As opposed to the adverse effects of trans fatty acids, epidemiological data show a low incidence in atherosclerotical cardiovascular disease in the Mediterranean region, where the diet includes a large quantity of monounsaturated fatty oils, which could reduce the low-density lipoproteins and cholesterol without increasing the triglyceride levels (*9*). Even though the majority of these studies have been made on olive oil, recent research performed in Mexico has shown that diets enriched with avocado pulp have the same cholesterol-lowering effects (*10*−*14*).

Avocado is not considered to be a primary source of oil, so few studies have been devoted to its extraction from the pulp. Werman (*15*) investigated the oil extraction from the whole fruit, including the seed, to study the effect of its consumption on rat liver metabolism. Curiel (*16*) patented the acetone extraction method, and the Marnys Co. (*17*) extracts the oil by drying the pulp and cold-pressing and markets the products as a cosmetic to improve skin elasticity.

This paper presents the study of the physical and chemical changes, the fatty acids profile, the trans fatty acid content, and the identification of volatile compounds of the oils extracted from avocado pulp *Persea americana* Mill., obtained by four

* Author to whom correspondence should be addressed (fax 52 59 11 32 931; e-mail necoechea203@axtel.net).
† Escuela Nacional de Ciencias Biológicas.
§ Violetas 203 La Florida Satélite.

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Table 1. Experimental Design for the Microwave Procedures

sample	14	12	13	5	7	6	2	1	9	10	4	8	11	3
sample (g)	300	300	300	300	300	300	350	250	370	300	350	229	300	250
time (min)	11	11	11	11	11	11	8	8	11	6.8	14	11	15	14

different methods. This paper also studies a new combined extraction method, microwave−squeezing, proposed by the authors.

MATERIALS AND METHODS

Raw Material. Avocado (*P. americana* Mill.) was obtained from a local market in Mexico City. The fruit was analyzed for proximal composition according to official AOAC techniques (*18*), to classify it by ripening stage. The selected batch of avocado was washed with water and detergent. Then it was manually peeled, the seed was removed, and it was ground in a mortar. This pulp underwent four different treatments for oil extraction.

Oil Extraction Treatments. *Microwave Treatment.* The avocado pulp was spread on the rotary plate of a domestic microwave oven, Samsung Co., 2450 MHz, 859 W, as calculated by the Buffler method (*19*), to form a uniform layer of ∼5 mm thick. The sample was placed in the oven and heated at high power level. Then the sample was removed from the plate and the oil extracted by squeezing, pressing the pulp manually through a cloth mesh. Preliminary experiments were carried out, and from those results a central composite experimental design was developed using Design-Expert software (version 5). **Table 1** shows the experimental design for the microwave method. This design had two variables: quantity of the sample (grams) and time of microwave exposure (minutes). The selected response variables were oil yield (percent) and amount of trans fatty acids (percent). The energy (E) for the microwaves was calculated for each of the experiments shown in **Table 1**, using the equation

$$E = Wt/m \quad (1)$$

where $W = 859$ W, which is the microwave oven power; t = time of microwave exposure in minutes; and m = quantity of the sample in grams.

Hexane Extraction. Avocado pulp was previously dehydrated at 70 °C in a vacuum oven at a working pressure of ≤100 mmHg, until the sample reached 27% moisture. Then the oil was extracted according to the Soxhlet method (AOAC 963.15). A few defatted antibumping agents were added to a 250 mL Erlenmeyer flask and dried for 1 h at 100 °C; it was cooled in desiccators and weighed. The thimble containing the dried sample was placed in the Soxhlet device, supporting it with glass beads. The dehydrating beaker was rinsed with 150 mL of petroleum ether, and the washing was added to the thimble. The sample was refluxed for 4 h, with the heat adjusted so the extractor siphoned ≥30 times. The flask was removed and the solvent evaporated on a steam bath. The flask was dried at 70 °C to constant weight (1.5−2 h).

Microwave−Hexane Combined Extraction. Three hundred grams of avocado paste was heated with microwaves for 11 min, using the microwave treatment described before. Then the oil was extracted using the Soxhlet extraction method (described above).

Acetone Extraction. The avocado oil was extracted using acetone as a solvent (*16*). Five hundred grams of avocado was comminuted to small particles of about 3 × 5 mm, after peeling and seed removal. Fruit particles with 1500 g of acetone were carried out at a temperature of ∼25 °C, at which most of the water present in the avocado fruit was extracted into the acetone phase. The other extraction operation of substantially water-free avocado with acetone solution was carried out at a temperature of ∼55 °C. All liquid solutions obtained from the extraction steps were admixed and cooled to ambient temperature, thus obtaining two main fractions, which were separated: (1) an upper layer of oil−acetone−water, which contained mainly the unsaponifiable matter and (2) a lower phase of oil−acetone−water, which contained the main fraction of avocado oil.

The acetone was removed by distillation and recycled to the extraction operation. The oil separated out as the upper phase above the aqueous phase.

Analytical Methods. *Physical and Chemical Properties.* The oil obtained with the different extraction methods was characterized using the following physical and chemical parameters (*20*): specific weight (Cc 10a-25), refractive index (Cc 7-25), iodine value (Cd 1-25), saponification value (Cd 3-25), acid value (Cd 3a-63), peroxide value (Cd 8-53), smoke point (Cc 9b-52), cold test (Cc 14-59), viscosity according to the Brookfield DV-1 method, and color measured in Lovibond equipment (Cc 13b-45).

Fatty Acid Analysis (AOCS Ce 1-62) (20). A gas chromatograph (Perkin-Elmer Auto System XL) was used with a flame ionization detector and a BPX 70 capillary column (60 m × 0.25 i.d. × 0.25 μm film), using a temperature program of 120−240 °C with a 4 °C/min gradient. The carrier gas was hydrogen, flowing at 10 mL/min and split 20:1. The detector and injector temperatures were 230 and 250 °C, respectively. Determination of cis and trans fatty acids was verified by comparison of retention times of test samples with those of reference standards and internal standardization.

Volatile Compounds (21). The volatile compounds from the different oils were extracted using a polydimethylsiloxane/carbowax/divinylbenzene fiber (PDMS/CAR/DVB) in the following way: 3 g of each oil was placed into a 10 mL vial and kept for 24 h at 20 ± 1 °C; the fiber was placed in the headspace and was exposed to the oil for 30 min a 40 °C. The fiber was then retracted into the needle and immediately transferred to the chromatograph. The fiber was desorbed for 5 min in the gas chromatograph injection port. For the volatile compounds analyses, a Hewlett-Packard 5890 gas chromatograph connected to a Hewlett-Packard 5985 mass spectrometer, with a DB 5-MS column (30 m × 0.25 i.d. × 0.25 μm film) was used, under the following conditions: oven temperature, 50 °C (5 min) then raised at 5 °C/min to 250 °C; injector and detector temperatures, 200 and 250 °C, respectively; helium flow, 1 mL/min. Tentative identification by mass spectral library search was performed.

Statistical Analysis. Multiple-range statistical analysis (Duncan) (*22*), at a 0.05 significance level, was used. The results obtained in the gas chromatograph were analyzed to determine the reproducibility of the method. No significant differences were found among extraction procedures. A second analysis was made to find out if the extraction methods could cause a significant difference in the fatty acid composition of the samples. A third analysis was performed to determine a significant difference of the fatty acid profile of the oil obtained with the acetone procedure when compared with the oils from the three other methods.

RESULTS AND DISCUSSION

The results of the proximal analysis of the avocado batch selected for this study were as follows: 77.3% moisture, 15.8% fat, 5.6% carbohydrates, 1.6% protein, 1.3% ash, and 0.4% crude fiber. The minimum fat level required in Mexico for the harvest of avocado is 15%, corresponding to the ripening stage, so the batch used for this study can be considered to be ripe.

Avocado Oil Extraction Yields. In the four different methods the extraction yields were obtained by comparing the amount of extracted oil to the previously determined value of 15.8% fat.

The oil extraction percentage (Y) as a function of the quantity of the sample (A) and the microwave exposure time (B) is presented in **Figure 1**. This surface response is the result of the central composite experimental design with two variables (**Table 1**). The surface response shows a correlation of the quantity of

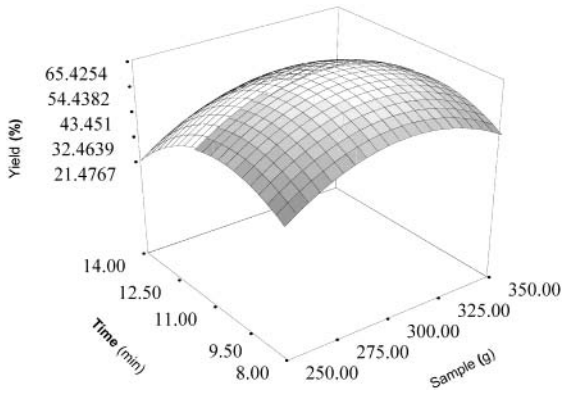

Figure 1. Surface response analysis of the oil extraction yield as a function of microwave exposure time and quantity of sample.

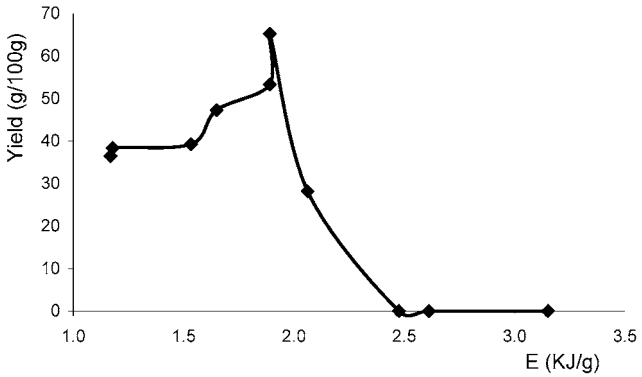

Figure 2. Oil yield (grams per 100 g) as a function of the microwave energy (kilojoules) applied to the avocado pulp (grams).

the sample and the microwave exposure time that follows a square model. This correlation is also significant, having a significance level lower than 0.05 and an $R^2 = 0.9734$. The equation so obtained is

$$Y = 8.03 + 0.33A - 0.64B - 1.14A^2 - 1.26B^2 \quad (2)$$

The highest extraction yield (65.2%) for the microwave−squeezing combined method was obtained when the sample weighed 300 g and the exposure time was 11 min.

The highest extraction yield obtained with the hexane extraction method in a Soxhlet extraction was 54%, using 150 mL of hexane per 10 g of sample (previously dehydrated to 27% moisture) and a 4 h extraction time.

The extraction yield obtained with the microwave−hexane method was 97% when 300 g of pulp was exposed to microwaves for 11 min, and then the oil was extracted using 150 mL of hexane per 10 g of sample during 4 h. This extraction yield is the highest for the four methods previously described, being particularly high when compared with the industrial average yield for olive oil, which is 86−87% (*23*).

Figure 2 shows how the intensity of the microwave energy applied (E = kJ/g of pulp) to avocado pulp affects the oil yield. When the energy is >2 kJ/g, the oil yield falls to its lower level. This energy level corresponds to a temperature in the pulp of >100 °C, which may cause the idioblastic oil cells to transform their structure and, in turn, to prevent the release of the oil. On the other hand, when the energy is ∼1.89 kJ/g, the highest levels of oil yield are obtained. This effect was observed under electron microscopy when the microstructural changes of avocado pulp processed with the four different methods were studied, and it is briefly described as follows. After the oil has been extracted by microwave−squeezing, the idioblastic oil cells appear to be empty with no major alterations. The hexane procedure causes the cells to become rough and irregularly shaped. When the acetone method is used, most of the oil remains inside the cells, and the strongest changes in the cellular structure are observed. The extraction yield obtained with the acetone method was 12%, which may be due to such effects.

Physical and Chemical Properties. Table 2 shows the physical properties of the oils extracted with the four different methods. The results obtained are relevant within the different methods only. The oil used for the analysis was not a refined oil.

The refractive index does not vary in a significant way among the four samples. All og the oils showed no significant difference in density, except for the oil extracted with acetone. On the other hand, the oils extracted with hexane and acetone show a higher viscosity; the oil extracted with acetone has the higher value. These results agree with those reported by Albi et al. (*24*), when they compared the effects of conventional and microwave heating in different edible oils. Their study concludes that the increase in density is due to the incorporation of oxygen into the fatty acids and that the increase in viscosity is due to the formation of dimers and polymers.

The color of the oils processed with microwaves was green, which is an indication that microwaves not only allow the extraction of the oil from the idioblastic oil cells (cells that contain the highest oil content) but also free the chlorophyll from the chloroplasts. **Table 2** presents the readings made on the Lovibond equipment. The oil extracted with hexane had a yellow color, corresponding to readings of 28 in the yellow, 0 in the blue, and 0.3 in the red scales. The color of the oil extracted with acetone had a dark color, with a value of 6 in the red scale. Kic Chemical (*25*) recommends a maximum value of 1.5 in the red scale for avocado oil, as read in the Lovibond equipment. The Official Mexican Norm for edible oils (NOM-F223) (*26*) establishes a maximum of 4.5 in the red scale. Given the above, we conclude that the oil extracted with acetone is not within the color standards.

Table 2 shows the chemical properties, such as the acid value that is a measure of the quantity of free fatty acids in the sample. The oils that were processed with solvents had a higher acid value than the ones processed with microwaves; the highest acid value was for the samples processed with acetone. When the current results are compared with the ones obtained by Albi et al. (*27*) for extra virgin olive oil (0.36% oleic acid) and olive oil (0.26% oleic acid), it can be seen that the acid values estimated in the samples processed with solvents are higher. On the other hand, those samples subjected to microwave processing have acid values within the ranges found by Albi et al. and the one specified as 0.5% oleic acid by the virgin olive oil Official Mexican Norm (NOM-F 109) (*28*).

Table 2 also shows the peroxide value obtained for the sample extracted with acetone. Such value is 400% higher than the value for the sample obtained by the microwave−squeezing method. These values agree with the ones reported by Albi et al. (*27*) for extra virgin olive oil (16.1 mequiv of O_2/kg of oil) and olive oil (11.2 mequiv of O_2/kg of oil) and also agree with the results of Mai (*29*), who did not find evidence of chemical modifications induced by the microwave heating. Yoshida (*30*) reports that the microwave exposure time needs to be very long to detect any alteration on the fatty acids.

The oil extracted using acetone had the lowest saponification value, having a difference of 73 mg of KOH/g when compared with the value of the oil extracted by squeezing. The saponifica-

Table 2. Physical and Chemical Properties of Avocado (*P. americana* Mill.) Pulp Oil Extracted with Four Methods

property[a]	oil extraction method			
	microwave + squeezing	microwave + hexane	hexane	acetone
density (g/mL)	0.9102 ± 0	0.9103 ± 0	0.9100 ± 0.0001	0.9010 ± 0.0002
refractive index	1.467 ± 0.0	1.467 ± 0.0	1.466 ± 0.002	1.465 ± 0.002
viscosity(cps)	15 ± 1	17 ± 1.3	20 ± 0.8	35 ± 1.8
color (Lovinbond)	yellow = 18	yellow = 24	yellow = 28	yellow = 20
	blue = 9.4	blue = 6.6	blue = 0	blue = 9.9
	red = 1.1	red = 1.2	red = 0.3	red = 6.0
acid value (% oleic acid)	0.144 ± 0.027	0.277 ± 0.015	0.65 ± 0.030	2.84 ± 0.040
peroxide value (mequiv of O_2/kg of oil)	3.70 ± 0.054	9.55 ± 0.074	10.68 ± 0.064	12.74 ± 0.300
saponification value (mg/KOH/g)	241 ± 0.28	235 ± 0.18	273 ± 0.84	168 ± 0.48
iodine value (Wijs)	87.6 ± 0.29	84.1 ± 0.13	82.1 ± 0.13	94.8 ± 0.475
smoke point (°C)	204 ± 0.5	203 ± 0.4	185 ± 0.8	142 ± 0.8
cold point (h)	14 ± 0.8	12 ± 0.9	16 ± 0.8	ND

[a] Average value of six samples. ND, not determined.

tion value has an inverse correlation with the molecular weight. These data, in addition to the sedimentation and turbidity observed in the oil extracted with acetone, suggest a possible presence of polymers derived from the oxidation compounds of fatty acids and, therefore, the presence of a greater amount of unsaponifiable material.

The iodine value is a direct measure of the quantity of double bonds. The results obtained for the iodine value agree with the data reported by Bora et al. (*31*), 77.6 for avocado oil. The results obtained are also very close to the range established by the Mexican Norm for olive oil (NOM-F 109) (*28*), which is 79.5−91. This shows that the compositions of olive and avocado oils are very similar, and this conclusion was corroborated with the gas chromatography analysis of the fatty acids that is presented further in this paper.

The smoke point is an indirect measure of the thermal stability of oils and is related to the free fatty acids contained in the oil. **Table 2** shows that the oils extracted with solvents (hexane or acetone) have the lowest smoke point values. The oils made from pulp exposed to microwaves have almost the same value. Kic Chemical Co. proposed 218 °C as the smoke point value for avocado oil. Vegetable oils have different values, such as 161 °C for olive and 232 °C for soy. Therefore, the smoke point measured in this study is within those intervals.

The cold point is a measure of the resistance of the fat to form crystals and, therefore, its resistance to storage at low temperatures. Kic Chemical Co. (25) proposes a minimum of 5.5 h for avocado oil crystallization. The results obtained in this study are over this recommended limit, except for the sample extracted with acetone, which was impossible to evaluate due to its turbidity.

Changes in the Fatty Acid Profile of Avocado Oil. Because this study proposes a novel extraction method, a trans fatty acid analysis was made for the samples described in **Table 1**. The surface response analysis obtained for the trans fatty acid variable (*A*), as a function of the quantity of the sample (*S*) and the exposure time (*t*), is shown in **Figure 3**. A square model was found, having a significance level of <0.05 and R^2 = 0.9285. The equation so obtained is

$$A = 0.1 + 0.023t + 0.024t^2 + 0.021M(t) \qquad (3)$$

Figure 4 shows how the intensity of the microwave energy applied (E = kJ/g) to avocado pulp affects the amount of generated trans fatty acids. When the energy density is >2 kJ/g, the trans fatty acids increase sharply to their higher level. This energy level corresponds to a temperature in the pulp of >100 °C. On the other hand, when the energy density is in the range of 1.50−1.89 kJ/g, the lowest levels of trans fatty acids are obtained.

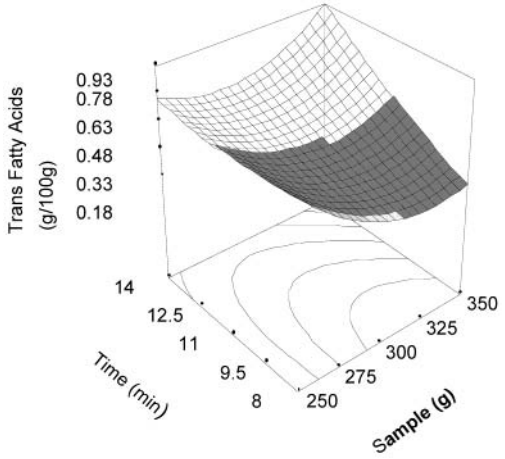

Figure 3. Surface response analysis of the trans fatty acid content of the oil extracted by microwave–squeezing.

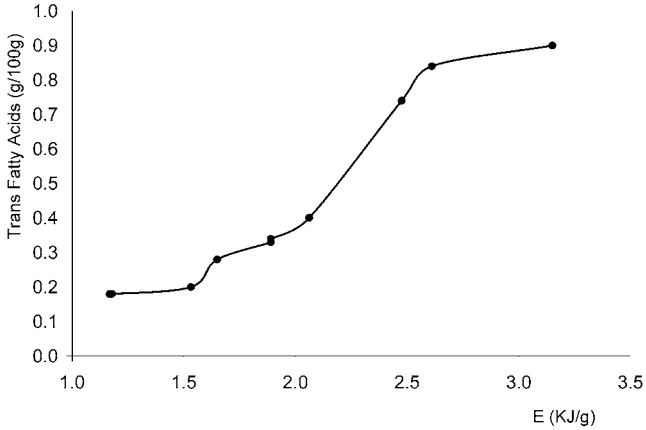

Figure 4. Amount of trans fatty acids in avocado oil (grams per 100 g) as a function of the microwave energy (kilojoules per gram).

Significant differences were found in the fatty acid content of the samples processed with the different extraction methods (**Table 3**), specifically for palmitic acid (16:1 cis), palmitoleic (16:1 trans), oleic (18:1 cis), linoleic (18:2 cis), and linolenic (18:3 trans). Palmitic acid was the major component in the microwave−squeezing processed oil, having a concentration of 21.1 g/100 g of oil. This value agrees with the results reported by Bora et al. (*31*). **Table 3** shows how the concentration of oleic acid is reduced with the microwave treatment. The samples

Table 3. Fatty Acid Profiles of the Avocado (*P. americana* Mill.) Pulp Oils Extracted by Four Different Methods[a]

	oil extraction method (g/100 g)			
fatty acid	microwave + squeezing	microwave + hexane	hexane	acetone
palmitic (16:0)	21.1	18.1	15.71	14.96
palmitoleic (16:1)	8.9	6.79	7.26	5.88
palmitelaidic (16:1)	0	0	0.16	0.14
stearic (18:0)	0.5	0.54	0.72	0.48
oleic (18:1)	52.04	56.45	60.28	60.02
elaidic (18:1)	0.29	0.09	0.3	0.45
linoleic (18:2)	14.89	15.24	13.66	15.31
linoleidate (18:2)	0.04	0.04	0.04	0.27
linolenic (18:3)	1.83	2.07	1.44	1.66
gadoleic (20:1)	0.22	0.52	0.21	0.5
arachidonic (20:4)	0.09	0	0.11	0.22
erucic (22:1)	0.09	0.06	0	0.14
total trans fatty acids	0.33	0.5	0.52	0.87

[a] Average of four samples.

processed with this treatment had a trans fatty acid concentration of <0.5 g/100 g of oil and thus can be considered as trans fatty acid free, according to the FDA (*8*).

In all of the oil samples, the fatty acids found in the highest concentrations are (in decreasing order) oleic (18:1ω−9), palmitic (16:0), linoleic (18:2ω−6), and linolenic (18:3ω−3). This agrees with a previous report by Sinyinda (*32*).

Table 3 shows that the fatty acid profiles of the oils extracted with hexane and acetone are very similar and resemble the one reported by Carranza et al. (*10*). The oils that were processed with microwaves, whether the extraction is by squeezing or hexane, have a similar profile, which can be due to the changes that microwaves originate on the fatty acid composition, as reported by Albi et al. (*24*).

The last statistical analysis showed that there are significant differences in the fatty acids profiles of the oil extracted with acetone and the oils processed with the other methods.

Volatile Compounds Identification in Avocado Oil. There are four volatile compounds when the oil is extracted by microwave−squeezing (**Table 4**): hexanal, octanal, nonanal, and β-caryophyllene. The largest number of volatiles appears when the oil is extracted with solvents and may be due to the effect of the thermal extraction with solvents and also to a greater decomposition effect on the fatty acids. **Table 4** shows a total of 36 identified volatile compounds. The samples exposed to microwaves contained terpenoids and aldehydes, such as hexanal (linoleic acid derivative), octanal, and nonanal (oleic acid derivatives). Hexanal has been reported to be a volatile compound present in avocado pulp, together with octanal and nonanal (*32*). This compound also indicates that lipid oxidation took place (*33*). These results correspond to the physical and chemical parameters presented earlier, as well as to some studies on the effect of microwaves on various foods and edible oils (*29, 30*).

The oil extracted with hexane contained propionic acid, decanol, 2,4-decadienal, and aromatic hydrocarbons such as tridecane and undecane, as well as terpeniods. These compounds

Table 4. Volatile Compounds in Avocado Oil (*P. americana* Mill.) Extracted by Four Different Methods

		oil extraction method			
RT (min)	identified compound	microwave + squeezing	microwave + hexane	hexane	acetone
5.16	hexanal	x	x		
7.34	benzene, 1,4-dimethyl			x	
8.12	benzene, 1,2-dimethyl			x	x
8.42	heptanal		x		
11.69	1,2,4-trimethylbenzene			x	
12.01	decane			x	
12.06	octanal	x	x		
14.33	*n*-octanal		x		
14.79	benzene, 4-ethyl-1,2-dimethyl			x	
15.37	undecane			x	
15.48	nonanal	x	x		
18.20	benzoic acid, 2-hydroxymethyl ester			x	
18.50	dodecane			x	
18.63	decyl aldehyde		x		
18.86	undecane, 2,6-dimethyl			x	
19.25	2-propanoic acid, 2-ethylhexyl ester			x	
21.20	*trans*,*trans*-2,4-decadienal				x
21.39	tridecane			x	
21.84	2,4-decadyenal		x		
21.85	*trans*,*trans*-2,4-decadienal (isomer)				x
22.66	α-cubebene		x		x
23.10	2-docen-1-al		x		
23.32	propanioc acid, 2-methyl-3-hydroxy-2,4,4-trimethylpentyl ester			x	
23.45	α-copaene		x		x
24.07	tetradecane			x	
24.64	β-caryophyllene	x	x		x
24.93	*trans*-α-bergamotene		x		
24.95	α-bergamotene				x
25.56	α-humolene		x		x
25.93	cyclotetradecane		x		
26.20	germacrene D				x
26.61	pentadecane			x	
26.71	(*E*,*E*)-α-farnesene				x
26.82	β-bisabolene				x
28.67	caryophyllene oxide		x		x
28.70	propanoic acid, 2-methyl-1-(1,1-dimethyl)-2-methyl-1,3-propamedyl ester			x	
	total identified compounds	4	15	15	12

have also been detected in avocado pulp (*32*). It should be noted that the largest number of aromatic hydrocarbons was detected in this sample. Meanwhile, the oil extracted with acetone contained mainly terpenoids, aldehydes, and short-chain fatty acids. Some of the terpenoids found were α-bergamotene, α-humulene, α-copaene, α-cubebene, α-farnesane, β-caryophyllene, and β-bisabolene. Dodecane and 2,4-decadienal were also identified.

Previous reports on the volatile compounds of avocado mention terpenoids such as the ones reported in this study (*32*, *34*). **Table 4** shows how the pattern of volatile compounds in a sample may vary according to the oil extraction method.

Siniyinda (*32*) reports that many oxidation compounds from lipid derivatives are present in the fresh mesocarp of avocado. Further studies are needed to understand the origin of the oxidation compounds found in the avocado oil processed by different extraction methods.

It may be concluded that the different extraction methods modify in various ways the physical and chemical characteristics of avocado, as well as the fatty acids and volatile compounds profiles of this fruit. The highest yield was obtained when using the combined microwave−hexane extraction method. The slightest modification to the characteristic of the oil was obtained with the microwave−squeezing method. The trans fatty acid amount generated in the microwave−squeezing method was under the limit proposed by the FDA. The compound hexanal was found only when the sample was exposed to microwaves. In general, it may be concluded that in this study, a greater deterioration of the oils was produced with solvents rather than microwaves.

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