OCL 2021, 28, 55
© M. Douzane *et al.*, Published by EDP Sciences, 2021
https://doi.org/10.1051/ocl/2021044

OCL Oilseeds & fats Crops and Lipids

Available online at:
www.ocl-journal.org

RESEARCH ARTICLE OPEN ACCESS

Physico-chemical and sensory evaluation of virgin olive oils from several Algerian olive-growing regions

Malika Douzane[1], Mohamed-Seghir Daas[1], Amel Meribai[2], Ahmed-Hani Guezil[2], Abdelkrim Abdi[1] and Abderezak Tamendjari[3,*]

[1] Agri-Food Technologies Research Division, National Institute of the Agronomic Research of Algeria (INRAA), El Harrach, Algiers, Algeria
[2] Faculty of Mechanical Engineering and Process Engineering, University of Science and Technology Houari Boumediene of Algiers (USTHB), Bab Ezouar, Algiers, Algeria
[3] Laboratory of Applied Biochemistry, Faculty of Natural and Life Sciences, University of Bejaia, Bejaia, Algeria

Received 26 June 2021 – Accepted 14 November 2021

Abstract – Olive cultivar diversity is rich in Algeria but most remain unexplored in terms of quality traits. This work aimed to evaluate the physicochemical and organoleptic quality of twenty olive oil samples belonging to four Algerian cultivars (*Chemlal*, *Sigoise*, *Ronde de Miliana* and *Rougette de Mitidja*) collected throughout the national territory. Physical-chemical and sensory results showed that 60% of the oils belong to the extra virgin category, while 40% were classified as "virgin olive oil". The results of the principal component analysis (PCA) revealed a great variability in fatty acids composition between the samples depending on the cultivar and origin. Oleic acid was the most abundant and varied between 64.84 and 80.14%. Extra virgin olive oils with quality attributes are eligible for a label. *Rougette de Mitidja*, *Ronde de Miliana* and *Sigoise* from Oran showed great potential.

Keywords: Algerian cultivars / olive oil / chemical composition / sensory analyses / principal component analysis

Résumé – Évaluation physico-chimique et sensorielle des huiles d'olive vierges de plusieurs régions oléicoles algériennes. La diversité des cultivars d'olives est riche en Algérie mais la plupart restent inexplorées en termes de caractères de qualité. Ce travail vise à évaluer la qualité physico-chimique et organoleptique d'une vingtaine d'échantillons d'huile d'olive appartenant à quatre cultivars algériens (*Chemlal*, *Sigoise*, *Ronde de Miliana* et *Rougette de Mitidja*) collectés sur l'ensemble du territoire national. Les résultats physico-chimiques et sensoriels ont montré que 60 % des huiles appartiennent à la catégorie extra vierge, tandis que 40 % ont été classées comme « huile d'olive vierge ». Les résultats de l'analyse en composantes principales (ACP) ont révélé une grande variabilité de la composition en acides gras entre les échantillons en fonction de la variété et de l'origine. L'acide oléique est le plus abondant et variait entre 64,84 et 80,14 %. Les huiles d'olive extra vierge avec des attributs de qualité sont éligibles à un label. *Rougette de Mitidja*, *Ronde de Miliana* et *Sigoise* d'Oran ont montré un bon potentiel.

Mots clés : Cultivars algériens / huile d'olive / composition chimique / analyse sensorielle / analyse en composantes principales

Highlight

- Quality of twenty olive oil belonging to four cultivars from different regions was studied.
- Physical-chemical and sensory results showed that 60% of the oils belong to the extra virgin category.
- Variability in fatty acids composition depends on the cultivar and origin.
- Some secondary cultivars showed a great potential.

*Correspondence: abderezakt@yahoo.fr

1 Introduction

The olive tree (*Olea europaea* L.) is one of the most prominent fruit trees in Mediterranean countries, accounting for 97.9% of the total area of olive trees in the world (Rallo *et al.*, 2018). More than 11 million ha of olive trees are grown in more than 47 countries, mainly in Spain (25%), Tunisia (13%), Italy (11%), Morocco (10%) and Greece (9%) (FAOSTAT, 2018). Algeria is one of the main producers of olives; olive trees have been ranked as the first fruit tree (Algerian Ministry of Agriculture). The area covered by olive trees has increased from 310 644 ha in 2010 (M.A.D.R, 2010) to 500 000 ha, in 2018 (M.A.D.R.P, 2018). The olive oil sector

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is increasingly considered as economic and social development of diverse regions, including Kabylia and Oranía. During the 2017/2018 campaign, Algeria produced 80 000 tons, ranking at the ninth position worldwide.

Virgin olive oil (VOO) extracted from fresh and undamaged fruits (*Olea europaea* L.), and appropriately processed, is a staple of the Mediterranean diet (Bedbabis *et al.*, 2010). Olive oil is widely appreciated by consumers (Caporale *et al.*, 2006) for its sensory properties (Angerosa *et al.*, 2004; Bendini *et al.*, 2007), nutritional and health benefits (Visioli and Galli, 1998). Several studies have highlighted the effectiveness of the bioactive compounds from olive oil in curing and prevention various chronic diseases, such as atherosclerosis, diabetes, cancer, neurodegenerative, and coronary heart diseases (Lou-Bonafonte *et al.*, 2012; Visioli *et al.*, 2018).

Olive oil quality is referred to international standards defined by several organizations (European Commission Regulation, 2016; Codex Alimentarius, 2017; IOC, 2018c; Conte *et al.*, 2020). Olive oil quality assessment was performed by physicochemical parameters, including free acidity content, peroxide value, specific UV spectrophotometric absorptions (K_{232} and K_{270}), and sensory evaluation (Gharbi *et al.*, 2015).

The olive oil quality, nutritional and sensory characteristics are associated with the chemical composition, which is the result of a complex interaction between several environmental, agronomic, and technological factors (El Riachy *et al.*, 2018). The cultivar, growing area, environmental conditions, soil, tree age, irrigation, fruit ripening, harvest time, fruit storage and processing system represent the important factors influencing the composition of olive oil (Gharbi *et al.*, 2015; Ben Rached *et al.*, 2017; Mele *et al.*, 2018; Faci *et al.*, 2021).

Algeria has an important potential to develop olive oil production, which could place it among the main producing and exporting countries. The quality of olive oil has not been consistently a priority, with only 15% of the quantity produced belonging to the category of virgin and extra virgin oils. Currently, there is a renewed interest in the production of quality olive oil.

The enhancement and improvement of olive oil require the study of its quality and chemical composition which must comply with international standards. This work has aimed to assess the quality of Algerian olive oil according to the cultivar and area of cultivation to valorize the best ones.

2 Materials and methods

2.1 Plant material and sampling

The present work was carried on four cultivars of the local population, namely *Chemlal*, *Sigoise*, *Ronde de Miliana* and *Rougette de Mitidja* from different olive-growing regions of the country. *Chemlal* is the most widely grown cultivar in Algeria; it represents 40% of the Algerian olive grove. The fruits are small (about 1.7 g) and used for oil production; the oil yield varies between 14 and 22%. *Sigoise* occupies 25% of the Algerian olive grove and is located in the west plains. This cultivar is mainly used for the production of table olives which is characterized by medium-sized fruits (3.5 g). *Ronde de Miliana* occupies a limited olive-growing area. It is a dual-use cultivar (table olive and olive oil). The oil yield is estimated between 16 and 20%. *Rougette de Mitidja* is a cultivar intended for the production of oil with a yield varying from 18–20%.

The olive oil samples (twenty) produced during the 2018–2019 olive-growing season was collected from various producers during the months of November–December 2018.

Origin of the plant material and some agronomical conditions of each geographical area were shown in Table 1 and Figure 1. The olive trees have not undergone any chemical treatment.

Extraction of olive oil was performed immediately after harvest. The quantity of olives used for extraction is equal to or greater than 300 kg. The modern (automatic) three-phase system with a hammer crusher, malaxer and centrifugation of the olive paste is used for the extraction of the oil. All samples were packed in amber glass bottles without headspace and stored at 4 °C until analysis. Different analyses were performed during the first ten of the month of January 2019 for all the samples.

2.2 Quality and physical indices

Free acidity (IOC, 2015a), peroxide value (IOC, 2016), and UV spectrophotometric indices (K_{232}, K_{270}) (IOC, 2015b) were determined. Physical characteristics as refraction index ($^{n}D^{20}$) (ISO, 2006), density (IUPAC, 1987), water content, and volatile matter (ISO, 2016) were also determined.

2.3 Sensory analysis

A sensory analysis (median of defects, median of fruitiness, and panel classification test) of the samples was performed by 10 selected and trained panelists (IOC certified panel leader). The profile sheet was used according to the IOC Mario Solinas competition for extra virgin olive oils (T.30/Doc. No.21, March 2018). The strengths of the positive (fruity, bitter, and pungent) and negative (fusty, winy, musty, muddy, rancid, metallic, and others) attributes were evaluated for each oil sample on a 10 scale. The sensorial evaluation results were estimated by the median, being valid when the coefficient of variation was less than 20 (IOC/T.20/Doc. No.15/Rev.10, 2018).

2.4 Colorimetric determination of total phenols

The total phenol content of the olive oil samples was determined by the Folin–Ciocalteu spectrophotometric method at 725 nm, using a gallic acid calibration curve (Gutfinger, 1981).

2.5 Fatty acid composition

The fatty acid composition of the oils was determined by gas chromatography (GC) as fatty acid methyl esters (FAMEs). FAMEs were prepared by cold transesterification with methanolic solution of potassium hydroxide (2N) according the method of European Commission implementing Regulation 2015/1833 amending Regulation (EEC) No. 2568/91. The solution containing the fatty acid methyl esters was injected in

Table 1. Origin of the plant material, some agronomical conditions of each geographical area and oil yield (%).

Code/Sample	Cultivar	Locations	Altitude	Latitude	Climat	Rainfall (mm)	Irrigation	Temperature (°C)	Soil	Oil content (%)
S1	*Sigoise*	Mouzaïa (Blida)	50 m	36° 36 N	Mediterranean	676.3	Drip	5–34	Sandy-clay	15
R1	*Rougette de Mitidja*	Mitidja (Blida)	50 m	36° 36 N	Mediterranean	676.3	Drip	2–38	Silty-stony	17
C1	*Chemlal*	M'chedellah (Bouira)	420 m	36° 36 N	Mediterranean	403.8	*Drip*	0–37	Stony-limestone	18
C2a	*Chemlal*	Larbaa-NathIrathen (Tizi Ouzou)	400 m	36° 38 N	Mediterranean	720.1	Without	4–35	Stony-limestone	18
C2b	*Chemlal*	Larbaa-NathIrathen (Tizi Ouzou)	400 m	36° 38 N	Mediterranean	720.1	Without	4–35	Stony-limestone	20
C3	*Chemlal*	Boumia (Batna)	875 m	35° 68 N	Semi-arid	247.38	Drip	−5–42	Silty-clay	18
C4	*Chemlal*	AïnTouila (Khenchla)	1129 m	35° 26 N	Semi-arid	356.8	Drip	2–35	Sandy	20
C5	*Chemlal*	Aïn Oussara (Djelfa)	800 m	35° 26 N	Semi-arid	275	Drip	0–45	Stony	14
Rm1	*Ronde de Miliana*	Khemis-miliana (Ain Defla)	330 m	36° 36 N	Mediterranean	527	Without	0–45	Sandy	16
C6	*Chemlal*	Bouira	442 m	36° 36 N	Mediterranean	403.8	Drip	0–37	Silty-clay	22
S2	*Sigoise*	Ain EL Arbaa (Ain-Temouchent)	100 m	35° 35 N	Mediterranean	316.2	Drip	6–35	Silt-arable	18
S3	*Sigoise*	Misserghin (Oran)	125 m	35° 35 N	Mediterranean	378	Drip	10–30	Stony	22
S4	*Sigoise*	Aïn Ouessara (Djelfa)	800 m	35° 26 N	Semi-arid	275	Drip	0–45	Stony	18
SC1	*Sigoise/Chemlal*	Sfissifa (Naama)	1200 m	32° 43 N	Semi-arid	184	Drip	1–41	Stony	18
SC2	*Sigoise/Chemlal*	Bouhdjar (Aïn-Temouchent)	141 m	35° 35 N	Mediterranean	316.2	Drip	6–35	Silty	21
C7	*Chemlal*	Ahnif (Bouira)	340 m	36° 32 N	Mediterranean	403.8	Drip	0–37	Clay and limestone	18
S5	*Sigoise*	Essenia (Oran)	91 m	35° 39 N	Mediterranean	378	Drip	5–31	Stony	20
C8	*Chemlal*	Ighzer Amokrane (Bejaia)	103 m	36° 31 N	Mediterranean	750	Drip	5–36	Red soil and stony	20
C9	*Chemlal*	Akbou (Bejaia)	331 m	36° 45 N	Mediterranean	750	Drip	4–36	Red soil and stony	20
C10	*Chemlal*	Benhar-Aïn Ouessara (Djelfa)	700 m	35° 35 N	Semi-arid	275	Drip	0–45	Stony (brown)	18

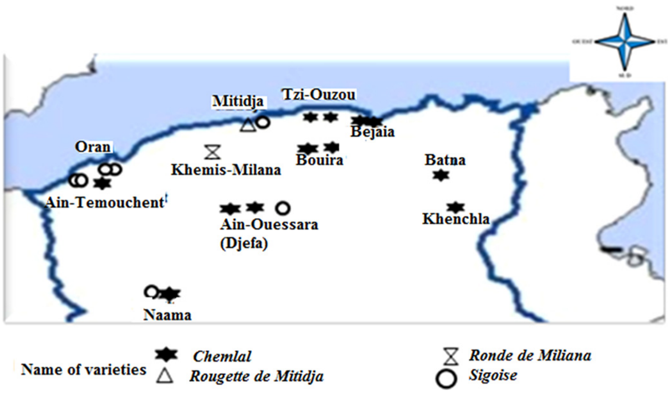

Fig. 1. Geographic origin and varieties of olive oil samples collected in Algeria.

split mode. Aanalysis was performed in a Chrompack CP 9002, equipped with a flame ionization detector (FID). An agilent capillary column (DB 23, 60 m length, 0.25 mm i.d, 0.25 μm film thickness), (Cyanopropyl at 50%) (USA) was used. The column temperature was isothermal at 200 °C and the injector and detector temperatures were 250 °C. Nitrogen as a carrier gas was used at flow rates of 1 mL/min. Fatty acids were identified by comparison of their retention times with those of standard reference compounds. Analyses were performed in duplicate.

2.6 Statistical analysis

All analyses were performed in triplicate, except for fatty acid composition, which is performed in duplicate; the results are presented as mean values. A simple analysis of variance was conducted according to the LSD test at the 5% threshold with GenStat Discovery Edition software. $P \geq 0.05$ indicates that the effect is considered non-significant.

The correlation between the different analytical parameters is treated by principal component analysis (PCA), to highlight associations of individuals or links between variables. The data were statistically processed by the Statistica software version 12.5.

3 Results and discussion

3.1 Oil content

The oil yield of the olives from the different samples is shown in Table 1. There are differences between the oil contents of the different cultivars. *Chemlal* from Djelfa (C5) has the lowest percentage (14%) and *Sigoise* from Oran (S3) has the highest percentage (22%). Al-Ruqaie *et al.* (2016) and Giuffrè (2017) showed that the cultivar significantly influences the oil content when samples come from the same harvest area.

The geographic origin of the samples also affects the oil content. For the same *Chemlal* cultivar, the yield varies from 14% for the sample from Djelfa (C5) to 22% for the sample from Bouira (C6). The same observation is noted for the cultivar *Sigoise*, whose yield varies from 15% (S1 from Blida) to 22% (S3 from Oran). The results are in agreement with those of Navas-López *et al.* (2020) who noted that genotype, environment and their interaction significantly affect the amount of oil.

3.2 Quality parameters

The parameters of the studied olive oils (Tab. 2) were within the limits of the European Commission implementing Regulation 2016/1227 amending Regulation (EEC) No. 2568/91 and IOC (2018b) and therefore the oils could be classified into the category of extra virgin olive oil, except samples of *Chemlal* from Tizi Ouzou (C2a and C2b), *Sigoise* from Ain-Temouchent (S2) and Djelfa (S4).

The region and cultivar had a highly significant effect ($P \leq 0.001$) on the free acidity, the peroxide index, the K_{270}, the water content, and significant effect ($P \leq 0.01$) on the K_{232}. Large variations in qualitative indexes according to the cultivar have shown by Piscopo *et al.*, 2016). Significant differences were observed in most of the quality parameters between the extra virgin olive oil of "*Sarıulak*" olive cultivar produced in three different locations (Antalya, Karaman, Mersin) in the south region of Turkey (Arslan *et al.*, 2013). The geographic area and environmental factors influence the characteristics of *Arbequina* oil (Borges *et al.*, 2017).

3.3 Physical indices

The physical characteristics of all samples are presented in Table 2. The refractive index increases with the degree of unsaturation of the fatty acids. Indeed samples with higher unsaturation showed a higher refractive index. Our results are within the limits [1.468–1.470] set by Codex Alimentarius (2017) standards for extra virgin oils.

Density (MV) depends on the chemical composition of the oil and temperature. Therefore, our results are in the range [0.910–0.916] of Codex Alimentarius (2017). A highly significant difference between the different samples studied ($P \leq 0.001$) according to refractive index and density.

3.4 Sensory analysis

The flavor and taste of olive oil are strongly correlated with its quality level and nutritional value. Sensory analysis of olive oils, based on median values of the positive and negative attributes carried out by a panel of trained tasters, is one of the most important evaluations used for virgin olive oil quality classification (Fernandes *et al.*, 2018). First, sensorial features of olive oils were analyzed and the oils with defects were discarded. Twelve samples belonging to the extra virgin olive oil category were selected for sensory analyses (Tab. 3).

The results of the organoleptic analysis of the extra virgin oils, presented in Table 4, showed great diversity in its sensorial profiles. The variation in bitterness intensity ranging from 1 to 2.5 and pungency from 1 to 2.5. These attributes are scored on a scale of 1 to 3. The type of green fruitiness was the same for the different oils, but it was nuanced by the intensity which varies from 6 to 9.

The results (Tabs. 3 and 4) indicated that the organoleptic note varies from one cultivar to another; the oils of the *Sigoise* cultivar from Blida (S1) and Aïn-Temouchent (S2) were

Table 2. Analytical characteristics of Algerian extra virgin olive oils at different olive growing region.

Sample	Free acidity (%)	Peroxide value (meq O_2/kg)	K_{232}	K_{270}	H%	$^nD^{20}$	Density	Total phenols (mg/kg)
S1	0.22 ± 0.01	5 ± 0.11	2.03 ± 0.02	0.17 ± 0.01	0.14 ± 0.01	1.4689 ± 0.0	0.911 ± 0.01	351.45 ± 0.11
R1	0.11 ± 0.01	2.5 ± 0.00	1.60 ± 0.03	0.15 ± 0.00	0.15 ± 0.01	1.4690 ± 0.0	0.910 ± 0.00	291.57 ± 0.04
C1	0.16 ± 0.01	4.5 ± 0.01	1.91 ± 0.04	0.15 ± 0.00	0.19 ± 0.02	1.4686 ± 0.0	0.913 ± 0.00	153.66 ± 0.07
C2a	1.0 ± 0.0	6 ± 0.04	1.95 ± 0.02	0.16 ± 0.01	0.21 ± 0.02	1.4681 ± 0.0	0.911 ± 0.01	126.87 ± 0.03
C2b	0.84 ± 0.01	13 ± 0.01	2.05 ± 0.05	0.18 ± 0.01	0.16 ± 0.01	1.4683 ± 0.0	0.912 ± 0.01	99.18 ± 0.06
C3	0.22 ± 0.00	3.5 ± 0.07	2.06 ± 0.02	0.16 ± 0.02	0.19 ± 0.01	1.4689 ± 0.0	0.911 ± 0.00	163.32 ± 0.14
C4	0.33 ± 0.01	2.5 ± 0.13	2.05 ± 0.01	0.16 ± 0.00	0.15 ± 0.01	1.4682 ± 0.0	0.916 ± 0.01	154.68 ± 0.11
C5	0.22 ± 0.01	5 ± 0.01	2.25 ± 0.02	0.2 ± 0.001	0.17 ± 0.01	1.4687 ± 0.0	0.910 ± 0.01	196.41 ± 0.03
Rm1	0.36 ± 0.00	6 ± 0.05	2.05 ± 0.03	0.16 ± 0.01	0.16 ± 0.01	1.4682 ± 0.0	0.912 ± 0.01	227.10 ± 0.01
C6	0.16 ± 0.01	2.50 ± 0.01	2.12 ± 0.01	0.17 ± 0.01	0.19 ± 0.01	1.4685 ± 0.0	0.916 ± 0.01	187.23 ± 0.0
S2	0.16 ± 0.00	3.5 ± 0.08	1.98 ± 0.03	0.16 ± 0.01	0.16 ± 0.00	1.4689 ± 0.0	0.916 ± 0.01	196.08 ± 0.02
S3	1.52 ± 0.0	3.5 ± 0.04	1.78 ± 0.02	0.15 ± 0.01	0.25 ± 0.01	1.4690 ± 0.0	0.915 ± 0.01	62.40 ± 0.11
S4	0.45 ± 0.01	3 ± 0.01	1.81 ± 0.03	0.13 ± 0.00	0.25 ± 0.03	1.4687 ± 0.0	0.914 ± 0.01	65.97 ± 0.08
SC1	0.78 ± 0.01	7 ± 0.13	2.01 ± 0.01	0.15 ± 0.01	0.24 ± 0.03	1.4686 ± 0.0	0.911 ± 0.00	96.66 ± 0.04
SC2	0.11 ± 0.00	7.5 ± 0.01	1.94 ± 0.01	0.14 ± 0.01	0.20 ± 0.01	1.4684 ± 0.0	0.915 ± 0.02	141.36 ± 0.02
C7	0.78 ± 0.01	8 ± 0.11	1.87 ± 0.02	0.17 ± 0.01	0.19 ± 0.02	1.4680 ± 0.0	0.911 ± 0.02	16.44 ± 0.09
S5	1.0 ± 0.0	7.5 ± 0.01	1.91 ± 0.03	0.15 ± 0.01	0.20 ± 0.02	1.4689 ± 0.0	0.914 ± 0.02	61.95 ± 0.07
C8	0.33 ± 0.1	7 ± 0.14	2.24 ± 0.03	0.18 ± 0.02	0.19 ± 0.02	1.4686 ± 0.0	0.915 ± 0.02	153.21 ± 0.02
C9	0.53 ± 0.01	10 ± 0.00	2.20 ± 0.02	0.18 ± 0.02	0.17 ± 0.01	1.4686 ± 0.0	0.912 ± 0.01	117.12 ± 0.04
C10	0.39 ± 0.01	21.5 ± 0.0	3.00 ± 0.00	0.19 ± 0.02	0.15 ± 0.00	1.4689 ± 0.0	0.913 ± 0.01	28.43 ± 0.01

Results are expressed as mean ± SD of three sample replicates.
Significance level: ***$P < 0.001$; **$P < 0.01$; *$P < 0.05$; NS = not significant. Free acidity: $P < 0.001$; Peroxide value: $P < 0.001$; K232: $P < 0.05$; K_{270}: $P < 0.001$; H%: $P < 0.001$; Density: $P < 0.001$; $^nD^{20}$: $P < 0.001$; TP: $P < 0.001$.

characterized by a fruity taste and a higher spicy median than other varieties.

The oil of *Rougette de Mitidja* cultivar from Blida (R1), with a very local diffusion, obtained a high score of 83.0, the best of all oils. It also showed a remarkable homogeneity as well as balanced attributes of intense fruity (9.0) and spicy (2.0) and bitter (2.0). The olive cultivar has been reported as one of the most crucial factors responsible for olive oil flavor variability (Tura *et al.*, 2008; Mele *et al.*, 2018). It is well established that the organoleptic properties of olive oil, which are strongly correlated to its geographical and varietal origins, are behind its wide commercialization and elevated market value (Rodney *et al.*, 2010; Borges *et al.*, 2017).

Samples of *Chemlal* cultivar, the most abundant olive cultivar in Algeria (40%), from different regions showed a remarkable difference in their sensory characteristics; it varies from ripe fruity with spicy and slightly bitter traits to medium green fruity with more pronounced fruit intensity, stronger spicy and bitter attributes. The same observation was noted for samples from the *Sigoise* cultivar where the oils have different sensory characteristics.

The cultivar factor has a very significant effect on sensory attributes. The aromatic notes depend on the volatile and phenolic compounds. The volatile composition of olive oil depends on several factors, such as the levels and activity of enzymes involved in different pathways (Angerosa, 2002).

Table 3. Results of the selective classification of the several oils.

Sample	Comment/Class
C2a	Defective oil
C2b	Defective oil
C4	Rancid oil
C6	Musty oil
S3	Highly defective oil
S4	Defective oil
S5	Fusty oil
C10	Fusty and musty oil
S1	Medium green fruity
R1	Intense green fruity
C1	Ripe fruity
C3	Ripe fruity
C5	Medium green fruity
Rm1	Medium green fruity
S2	Intense green fruity
SC1	Light green fruity
SC2	Ripe fruity
C7	Light green fruity
C8	Medium green fruity
C9	Medium green fruity

Table 4. Results of the detailed sensory analysis of the olive oils.

Sample	Olfactory sensations					Gustatory-retroasal sensations							Olfacto-gustatory final sensation		Final score
	Fruity olive	Other fruit	Green	Other positive feelings	Harmony	**Olive fruity**	Soft	Bitter	Pungent	Green	Other positive feelings	Harmony	**Complexity**	Persistance	
S1	6.5	2	2	2	18	8.5	2	1.5	2.5	2	2	17	7	8	77.0
R1	7	2.5	2	2	18.5	9	2.5	2	2	2	2.5	18	8	8	83.0
C1	5	1.5	1	1.5	15	6	2.5	1.5	2	1	2	16	5	6	65.5
C3	5	1.5	1	1.5	16	6	2.5	1.5	1	1	1.5	15.5	5	5	64.0
C5	6	2	1.5	2	18	8	2	2.5	2	1.5	2	17	7	8	77.0
Rm1	5.5	2	1.5	2	16.5	7	2.25	2	2	2	2	17.25	7.25	7	71.0
S2	6	2	2	2	17.5	7.5	2	2	2	2	2	17	8	7	80.0
SC1	6	2	1.5	2	17	7	2	1.5	1.5	1	2	18	6	7	73.5
SC2	5	1	1	1	15	6	2	2	2	1	1.5	15	5	6	65.0
C7	5	2	1.5	2	17	7	3	1	1	1	2	17	7	6	72.5
C8	6	2	1.5	2	17	7.5	2	1	1.5	1.5	2	18	8	7	77.0
C9	6	2	1.5	2	17	6.5	3	1.5	1.5	1.5	2	17	6	6	72.5

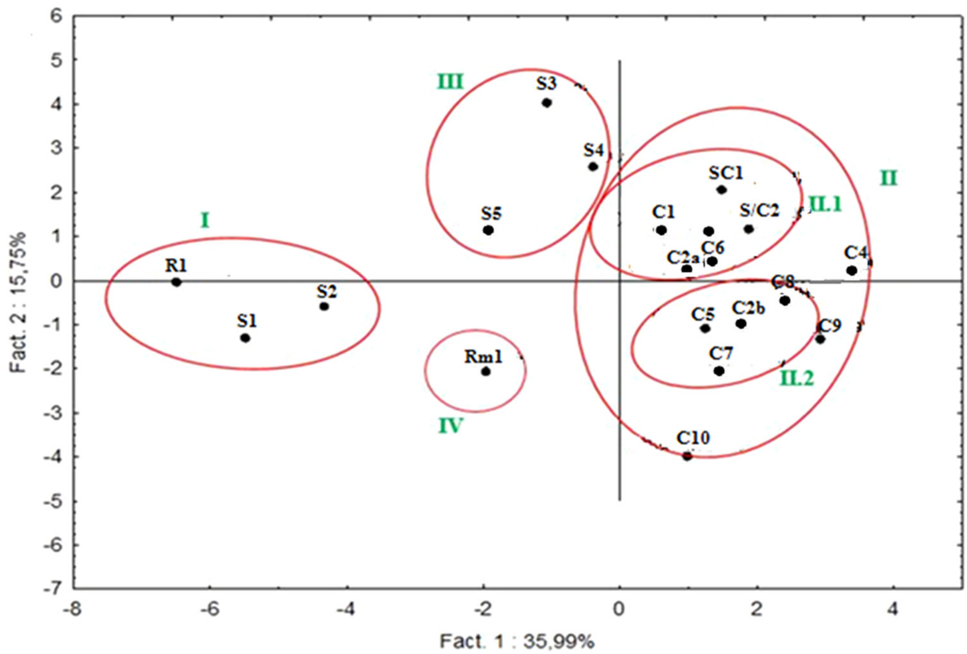

Fig. 2. Projection of the individuals according to the different principal components as plane of projection of the axis 1–2.
The name of samples is indicated by abbreviation (R: *Rougette de Mitidja*; S: *Sigoise*; C: *Chemlal*; Rm: *Ronde de Miliana*) and number (indicate origin). S1: *Sigoise* (Mouzaia, Blida); R1: *Rougette of Mitidja* (Blida); C1: *Chemlal* (M'chedellah, Bouira); C2a: *Chemlal* (Larbaa-Nath Irathen, Tizi Ouzou); C2b: *Chemlal* (Larbaa-Nath Irathen, Tizi Ouzou); C3: *Chemlal* (Boumia, Batna); C4: *Chemlal* (Aïn Touila, Khenchla); C5: *Chemlal* (Aïn Ouessara, Djelfa); Rm1: *Ronde of Miliana* (Khemis-Miliana, Ain Defla); C6: *Chemlal* (Bouira); S2: *Sigoise* (Ain EL Araba, Ain-Temouchent); S3: *Sigoise* (Misserghin, Oran); S4: *Sigoise* (Aïn-Ouessara, Djelfa); SC1:*Sigoise/Chemlal* (Sfissifa, Naama); SC2: *Sigoise/Chemlal* (Hammam Bouhdjar, Ain-Temouchent); C7: *Chemlal* (Ahnif, Bouira); S5: *Sigoise* (Essenia, Oran); C8: *Chemlal* (Ighzer Amokrane, Bejaia); C9: *Chemlal* (Akbou, Bejaia); C10: (Benhar Aïn-Ouessara, Djelfa).

3.5 Total phenols

The quality of olive oil is significantly related to polyphenols content (Benlemlih and Ghanam, 2016). The total phenol content of the olive oil ranged from 46.29 to 351.45 mg/kg (Tab. 2). A high significant difference ($P < 0.001$) between the different samples from different regions and varieties was noted. These results are lower than those recorded on extra virgin olive oil of Algerian varieties (Douzane *et al.*, 2013).

These low concentrations could be attributed to the olive oil extraction process in which most mills use the conventional three-phase centrifuge where a quantity of water has been added during the extraction process which has led to losses of phenolic compounds, vitamins, and aromatic components. It was reported that the two-phase decanter provides an oil rich in total polyphenols, ortho-diphenols, lower acidity, and better organoleptic quality compared to the three-phase press (Del Caro *et al.*, 2006). Besides the cultivar, the degrees of ripening of the olives and the environmental conditions influence the concentration of phenolic compounds (Škevin *et al.*, 2003). A negative correlation ($r = -0.88$) between drupe ripening degree and phenolic content of VOOs was found (Rotondi *et al.*, 2004).

According to Borges *et al.* (2017), significant variations ($P < 0.05$) in the concentration of minor bioactive constituents were observed among oils from different growing areas, not only between Spanish and Brazilian samples but even within areas of the same country for *Arbequina* cultivar.

3.6 Fatty acid composition

The fatty acid composition is shown in Table 5. The most representative fatty acids are oleic, linoleic, palmitic, and stearic, which represent 98% of the composition of total fatty acids. Oleic acid was the most abundant and varied between 64.84 and 80.00%. The large-fruited varieties showed the highest amounts of oleic acid (*Sigoise S1*: 75%; *Ronde de Miliana Rm*: 73.88%; *Rougette de Mitidja (R2*: 80.14%) and lower levels in small-fruit varieties (*Chemlal*: 67%), a similar result as reported by Faci *et al.* (2021) who studied C*hemlal* of Tizi-Ouzou. These results corroborated with those obtained previously by Douzane (2012) for the same varieties: *Sigoise* (71.40%), *Ronde de Miliana* (80.18%) and *Rougette de Mitidja* (74.80%) collected from Olive production station (Sidi Aich, southern Bejaia). Lower percentages were noted for the *Chemlal* cultivar produced in several regions (Douzane, 2012). Algerian *Chemlal* cultivar presents a composition very close to the Tunisian cultivar "*Chemlali*" which contain low oleic acid and high concentrations of linoleic and palmitic acids (Manai *et al.*, 2007).

Linoleic acid which was the dominant polyunsaturated fatty acid ranged from 6.80% to 11.70%, while linolenic acid (C18:3) was the minor and ranged from 0.56% to 0.77%. The levels of linoleic acid are inversely related to oleic acid. According to Sánchez Casas *et al.* (1999), for better preservation of oils' quality, their linoleic acid content shouldn't be upper than 10%. Lower levels of oxidative stability have been noted in oils containing high proportions of linoleic acid (Pardo *et al.*, 2021). Also, Montaño *et al.* (2016) noted that oxidative stability was clearly correlated positively with oleic acid (R = 0.688) and negatively with linoleic acid (R = −0.710).

Palmitic acid, the major saturated fatty acids showed an important variation between samples, it ranged from 8.62% in *Rougette de Mitidja* cultivar (R2) to 17.57% in *Chemlal* cultivar (C5). All samples of *Chemlal* had high value (superior to 14%).The other varieties presented an intermediate value (13.24% for the *Ronde de Miliana* cultivar (Rm1), between 10.62 and 13.21% for the *Sigoise from different orogins*. Statistical analysis revealed a highly significant difference ($P < 0.001$) between the different samples of a different cultivar.

The values of fatty acids comply with the limits required by the European Commission implementing Regulation (2016/1227) and the International Olive Oil Council method (IOC, 2018a) on the characteristics of olive oils.

The percentages of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) and the ratios of PUFA/SFA and oleic/linoleic acids in all samples were also evaluated. It was observed that the oleic acid, the MUFA/ PUFA ratio, and the oleic/ linoleic ratio of the varieties with large medium fruits (*Sigoise*, *Ronde de Miliana*, and *Rougette de Mitidja*) are the highest and are clearly distinguished from the rates of "population cultivar" of small-fruit (*Chemlal*) (Tab. 5). Some results on the *Chemlal* cultivar are comparable to those observed by Louadj and Giuffrè (2010); however, our samples were characterized by a broad variation in the mentioned parameters above, due probably to the large geographical origins.

The results obtained in this work showed that the distribution of fatty acids is greatly influenced by olive cultivar. They agree those of others authors (Cicatelli *et al.*, 2013; Fuentes *et al.*, 2015; Cherfaoui *et al.*, 2018). However, many researchers have shown that geographical location has a significant effect. Palmitic acid, oleic acid, linoleic acid, and wax content were found to be significantly affected by the growing region for some cultivars (Rodney *et al.*, 2010). Noorali *et al.* (2014) noted that the fatty acid profiles could be used to separate olive samples according to their cultivar and growing area, respectively, the fatty acid profile was significantly affected by the growing area for almost all cultivars.

3.7 Multi dimensional analysis

The confrontation between the correlations circle of variables and the individual projections (Fig. 2) allowed for determining the characteristics of individuals according to their physicochemical characteristics, with the plane axis. Thus, axis 2 permitted us to distinguish that *Chemlal* cultivar has been regrouped for highlighting two subgroups, this is caused by the existence of subspecies within *Chemlal* cultivar to know as *Chemlal* of Tizi-Ouzou, precocious *Chemlal* of Tazmalt, *Chemlal* of Oued-Aissa, and Ali-Sharif's white *Chemlal*. The most abundant olive cultivar in Algeria, *Chemlal*, dominated Algerian olive orchards (40%), probably owing to its unique adaptation to various pedoclimatic conditions (Haddadi and Yakoub-Bougdal, 2010). *Chemlal* cultivar could be dispersed as a clone.

The medium-fruit cultivar *Ronde de Miliana* (Rm1) formed a single group, a sign of non-existence of a parental link with other varieties; the same results were noted previously by Douzane (2012). The large-fruited cultivar (*Sigoise* and *Rougette de Mitidja*) formed distinct groups. The heterogeneity of *Sigoise* could be connected to the existence of a mixture within the orchard of producers.

The individual projection allows us to distinguish the different groups (Fig. 2). This structure characterization was made according to the physicochemical analyzes.

Principal component analysis (PCA) allows us to define four groups. The individuals of Group I had the highest values of C18:1 (78.90%), refractive index (1.4690) as well as the ratios C18:1/C18:2 (11.63) and MUFA/ PUFA (10.63). Besides, they have low C16: 0 (9.69%), C16: 1 (0.78%) and C18:2 (6.86%).

Group II represented by the majority of individuals, was divided into two distinct sub-groups. Subgroup II.1 where its individuals had high humidity values (0.2%) and C18:2 (10.14%), low values of C18:1 (69, 6%) and polyphenols (1137.64 mg/kg). Subgroup II.2, the individuals had high values of peroxide index (8.6 meq O_2/kg), K_{232} (2.19), and K_{270} (0.186). They are relatively low in C18:1/C18:2 (6.878), C18:1 (68.5%) and nD20 (1.4682). Group III was represented by individuals that had higher humidity values (0.23%), C20:1 (0.31%), and C18:3 (0.71%). They presented a low peroxide index (4 meq O_2/kg), K_{270} (0.147), and K_{232} (1.830). *Ronde de Miliana* cultivar (Rm1) formed a separate group (group IV) with high values of C18:0, C18:1 (73.88%), and an acceptable level of polyphenols (227.12 mg/kg). It has low values of humidity (0.17), acidity (0.36%) and C18:2 (7.46%).

The concept of quality in olives is complex, and numerous traits might be considered. Different definitions may apply according to the point of view and final goal of producers, traders, consumers, and/or nutritionists. The olive oil composition of cultivar results from a very complex multivariate interaction between the genotypic potential and the environmental, agronomic, and technological factors that characterize fruit growth and ripening as well as oil extraction and storage (Lavee and Wodner, 1991). Some olive varieties like *Chemlal* are diffused as a clone. No genetic variation exists, therefore between the individuals. All variations in the final product are consequently attributable to environmental and physical factors. The mechanisms underlying environmentally-caused variations in oil composition are for the most part unknown. The results of previous studies (Ben Temime *et al.*, 2006; Borges *et al.*, 2017) have highlighted the effect of cultivar–environment interaction in the expression of the quality of olive oil. The changes in oil composition of the Tunisian *Chetoui* cultivar according to the plantation origin were studied (Ben Temime *et al.*, 2006). The results showed considerable variability in oil composition. The characteristics of the EVOO *Arbequina* from Brazil in comparison with Spanish *Arbequina* from different regions were recently studied (Borges *et al.*, 2017). The findings reveal that geographic and climate aspects of producing areas may significantly influence the quality and composition of *Arbequina* olive oil.

Table 5. Fatty acid composition (%) of olive oil samples resulting from several Algerian olive-growing regions.

Sample	C16:0	C16:1ω7	C17:0	C18:0	C18:1ω9	C18:2ω6	C18:3ω3	C20:0	C20:1ω9	C22:0	SFA	MUFA	PUFA	C18:1ω9/ C18:2ω6	MUFA/PUFA
S1	10.62 ± 0.13	0.91 ± 0.11	0.08 ± 0.01	1.70 ± 0.08	79.10 ± 0.79	6.08 ± 0.10	0.77 ± 0.08	0.20 ± 0.01	0.30 ± 0.04	0.20 ± 0.02	12.80 ± 0.7	80.31 ± 1.0	6.85 ± 0.6	13.01 ± 0.9	11.72 ± 0.9
R1	8.62 ± 0.16	0.66 ± 0.04	0.00	2.32 ± 0.05	80.14 ± 0.00	6.67 ± 0.80	0.69 ± 0.06	0.36 ± 0.02	0.35 ± 0.02	0.26 ± 0.03	11.56 ± 0.6	81.15 ± 1.01	7.36 ± 0.8	12.01 ± 0.8	11.03 ± 0.55
C1	14.32 ± 0.18	1.72 ± 0.06	0.10 ± 0.01	1.83 ± 0.09	70.71 ± 0.13	9.97 ± 0.9	0.51 ± 0.01	0.29 ± 0.00	0.32 ± 0.01	0.19 ± 0.01	16.73 ± 0.9	72.75 ± 0.9	10.48 ± 0.9	7.09 ± 0.66	6.94 ± 0.18
C2a	15.43 ± 0.21	1.67 ± 0.01	0.00	2.20 ± 0.01	70.07 ± 0.09	9.39 ± 0.9	0.57 ± 0.03	0.32 ± 0.03	0.34 ± 0.00	0.00	17.95 ± 1.0	72.08 ± 0.9	9.96 ± 0.7	7.46 ± 0.58	7.24 ± 0.23
C2b	16.25 ± 0.26	2.09 ± 0.09	0.08 ± 0.01	1.87 ± 0.10	68.94 ± 0.15	9.28 ± 0.88	0.66 ± 0.05	0.29 ± 0.01	0.30 ± 0.02	0.19 ± 0.01	18.68 ± 1.11	71.33 ± 0.8	9.94 ± 0.8	7.43 ± 0.60	7.18 ± 0.33
C3	13.86 ± 0.13	1.65 ± 0.16	0.09 ± 0.02	1.89 ± 0.08	69.59 ± 0.56	11.54 ± 1.0	0.50 ± 0.01	0.31 ± 0.04	0.31 ± 0.02	0.22 ± 0.03	16.37 ± 0.9	71.55 ± 0.9	12.04 ± 1.1	6.03 ± 0.42	5.94 ± 0.18
C4	17.57 ± 0.15	2.48 ± 0.03	0.08 ± 0.03	1.84 ± 0.06	64.84 ± 0.70	11.70 ± 1.0	0.68 ± 0.08	0.32 ± 0.02	0.29 ± 0.00	0.16 ± 0.00	19.97 ± 1.2	67.61 ± 0.7	12.38 ± 1.1	5.54 ± 0.18	5.46 ± 0.20
C5	14.13 ± 0.22	1.72 ± 0.01	0.08 ± 0.01	1.90 ± 0.12	70.12 ± 0.80	10.92 ± 0.9	0.53 ± 0.03	0.28 ± 0.00	0.28 ± 0.01	0.00	16.39 ± 1.0	72.12 ± 0.8	11.45 ± 0.9	6.42 ± 0.56	6.30 ± 0.45
Rm1	13.24 ± 0.51	1.04 ± 0.09	0.00	3.06 ± 0.09	73.88 ± 1.0	7.61 ± 0.88	0.50 ± 0.01	0.39 ± 0.05	0.24 ± 0.04	0.00	16.69 ± 0.9	75.16 ± 0.9	8.11 ± 0.7	9.71 ± 0.71	9.27 ± 0.66
C6	15.42 ± 0.11	1.72 ± 0.13	0.08 ± 0.04	2.08 ± 0.10	69.06 ± 0.95	10.14 ± 1.0	0.56 ± 0.02	0.36 ± 0.04	0.35 ± 0.06	0.18 ± 0.03	18.12 ± 1.3	71.13 ± 0.8	10.70 ± 0.9	6.81 ± 0.18	6.65 ± 0.76
S2	9.83 ± 0.26	0.77 ± 0.12	0.00	2.76 ± 0.05	77.45 ± 1.0	7.84 ± 0.8	0.75 ± 0.07	0.25 ± 0.03	0.29 ± 0.05	00	12.84 ± 0.8	78.51 ± 0.9	8.59 ± 0.8	9.88 ± 0.7	9.14 ± 0.75
S3	10.30 ± 0.23	0.97 ± 0.06	0.07 ± 0.01	2.11 ± 0.11	73.48 ± 0.88	11.47 ± 1.1	0.84 ± 0.09	0.26 ± 0.01	0.36 ± 0.04	0.12 ± 0.01	12.86 ± 0.8	74.81 ± 1.0	12.31 ± 1.1	6.41 ± 0.20	6.08 ± 0.45
S4	13.21 ± 0.15	1.51 ± 0.10	0.16 ± 0.00	1.99 ± 0.16	72.96 ± 1.2	8.93 ± 0.9	0.62 ± 0.04	0.29 ± 0.05	0.29 ± 0.02	0.00	15.65 ± 0.0	74.76 ± 0.9	9.55 ± 0.9	8.17 ± 0.66	7.83 ± 0.56
SC1	14.12 ± 0.13	1.65 ± 0.09	0.10 ± 0.01	2.14 ± 0.12	69.58 ± 0.9	10.50 ± 1.1	0.59 ± 0.05	0.42 ± 0.06	0.36 ± 0.05	0.26 ± 0.04	17.04 ± 0.10	71.59 ± 0.7	11.09 ± 0.9	6.63 ± 0.33	6.46 ± 0.34
SC2	15.36 ± 0.27	1.73 ± 0.12	0.07 ± 0.02	1.88 ± 0.13	68.26 ± 1.0	11.14 ± 1.15	0.56 ± 0.03	0.33 ± 0.01	0.35 ± 0.04	0.15 ± 0.01	17.79 ± 0.13	70.34 ± 0.7	11.70 ± 0.9	6.13 ± 0.30	6.01 ± 0.64
C7	16.85 ± 0.15	1.82 ± 0.06	0.00	1.93 ± 0.09	70.26 ± 1.1	8.28 ± 0.88	0.52 ± 0.01	0.32 ± 0.04	0.20 ± 0.01	0.00	19.10 ± 1.01	72.08 ± 0.9	8.80 ± 0.8	8.49 ± 0.66	8.19 ± 0.52
S5	11.44 ± 0.26	1.27 ± 0.13	0.00	2.12 ± 0.08	75.12 ± 0.9	8.55 ± 0.9	0.67 ± 0.06	0.28 ± 0.00	0.29 ± 0.03	0.20 ± 0.01	14.04 ± 0.11	76.68 ± 0.8	9.22 ± 0.9	8.79 ± 0.60	8.32 ± 0.66
C8	16.77 ± 0.11	2.17 ± 0.11	0.00	1.85 ± 0.10	66.91 ± 0.88	10.72 ± 1.4	0.62 ± 0.04	0.35 ± 0.06	0.35 ± 0.04	0.22 ± 0.03	19.19 ± 1.12	69.43 ± 0.6	11.34 ± 1.0	6.24 ± 0.5	6.12 ± 0.45
C9	16.82 ± 0.13	2.27 ± 0.03	0.00	1.86 ± 0.06	66.30 ± 0.9	11.41 ± 1.3	0.67 ± 0.05	0.33 ± 0.04	0.30 ± 0.03	0.00	19.01 ± 1.00	68.87 ± 0.7	12.08 ± 1.0.	5.81 ± 0.2	5.70 ± 0.22
C10	13.15 ± 0.22	1.73 ± 0.11	0.00	2.25 ± 0.08	71.89 ± 0.9	9.65 ± 0.88	0.60 ± 0.04	0.30 ± 0.03	0.21 ± 0.02	0.17 ± 0.01	15.87 ± 0.23	73.83 ± 0.9	10.25 ± .09	7.45 ± 0.5	7.20 ± 0.56

ND: Not detected.

Results are expressed as mean ± SD of three sample replicates. SFA: saturated fatty acids sum; MUFA: monounsaturated fatty acids sum; PUFA: polyunsaturated fatty acids sum.

Significance level: ***$P < 0.001$; **$P < 0.01$; *$P < 0.05$; NS = not significant. C16:0 – $P < 0.001$; C16:1ω7 – $P < 0.001$; C17:0 – $P < 0.001$; C18:0 – $P < 0.001$; C18:1ω9 – $P < 0.001$; C18:2ω6 – $P < 0.001$; C18:3ω3 – $P < 0.001$; C20:0 – $P < 0.001$; C20:1ω9 – $P < 0.001$; C22:0 – $P < 0.001$; C18:1ω9/C18:2ω6 – $P < 0.001$; MUFA/PUFA – $P < 0.001$.

4 Conclusion

The results showed that the cultivar plays an important role in the qualitative characteristics and sensory attributes of olive oils. The oil of *Rougette de Mitidja* cultivar from Mitidja (R1) showed the best sensory and physicochemical results. It also exhibited the best levels of oleic acid, qualifying it as the best extra virgin olive oil in Algeria for the 2018/2019 olive season. *Ronde de Miliana* (Rm1) also showed great potential.

Many other olive cultivars are unexplored in terms of quality traits, more effort should be made to assess them. On the other hand, olive growers must be encouraged to promote the local olive-growing heritage by cultivating varieties approved by the National Center for seeds and plants Control and Certification (CNCC).

Acknowledgements. The authors are grateful to the private olive growers for the plant material used in the experiments.

Conflicts of interest. The authors declare that they have no conflicts of interest in relation to this article.

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Cite this article as: Douzane M, Daas M-S, Meribai A, Guezil A-H, Abdi A, Tamendjari A. 2021. Physico-chemical and sensory evaluation of virgin olive oils from several Algerian olive-growing regions. *OCL* 28: 55.