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Physicochemical Changes in *Baladi* Olive Oil as a Function of Production Area and Extraction System in North Lebanon

Mireille Serhan[1*], Houda Younes[2] and Jessica Chami[2]
[1]Faculty of Health Sciences,University of Balamand, Deir El Balamand, P.O. Box 100, Tripoli,Lebanon
[2]Faculty of Sciences,University of Balamand, Deir El Balamand, P.O. Box 100, Tripoli, Lebanon

***Corresponding Author:** Dr. MireilleSerhan, Faculty of Health Sciences, University of Balamand, Deir El Balamand, P.O. Box 100 Tripoli, Lebanon; Tel: +9616 931952 Ext. 5206; Fax: +9616 931952 Ext. 5201 ; E-mail: mireille.serhan@balamand.edu.lb

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Abstract

Objectives: This paper studies the effect of the production area and the extraction system on the physicochemical attributes of *Baladi* olive oil (n=25) from five different districts in North Lebanon, during crop season 2013/2014.

Methods: Free acidity, peroxide value (PV),free fatty acids (FFAs), refractive index, total carotenoids, total phenols and oxidative stability were carried out following the analytical methods described in Regulations EEC/2568/91 and later modifications of the Commission of the European Union.

Results: Analysis of the extraction system's (pressure and three-phase) influence on the parameters determined presented statistical significant differences for acidity, peroxide index, refractive index and oxidative stability ($p<0.05$). Fatty acid composition and total carotenoids revealed statistical significant differences among different production areas ($p<0.05$). Total phenolic content was influenced by neither the extraction systems nor the production area. Oxidative stability showed positive significant correlation with the following physicochemical parameters (phenols, oleic to linoleic ratio and monounsaturated fatty acids to polyunsaturated fatty acids ratio) and negative significant correlation with other parameters (polyunsaturated fatty acids, peroxide value and acidity).

Conclusion: The analyzed olive oil samples were generally of higher acceptable quality. Future related studies are still needed to further confirm the Lebanese olive oil characterization.

Keywords: *Baladi* olive oil; Physicochemical parameters; Extraction system; Production area; Quality.

1. Introduction

Olive oil is well recognized for its quality and nutritional value that distinguish it from other vegetable oils. Due to its balanced composition, olive oil has been related to many beneficial health effects including anti-inflammatory properties, antioxidant properties and reduced risk of obesity, cardiovascular disease, hypertension, Type 2 diabetes and cancer [1-4].

In the Mediterranean region, olive oil comprises part of the culture, one of the main diet components, a very important export product and an extra income source.

In Lebanon, the olive cultivation is an essential part of the Lebanese agriculture which is 5.8% of the gross domestic production. The olive trees cover 20% of the total cultivated area (57,600 ha) and 43% of permanent crops area. Around 40% of the cultivation and 45% of the olive mills are located in North Lebanon.

In 2005, Lebanon had 492 olive mills; 87% of which applied traditional pressing system, 10% applied 3-phase continuous extraction system and 3% applied 2-phase continuous extraction system. In 2010, the olive mills increased to 550 with 85% using traditional pressing methods [5].

Despite the noticeable constraints in the Lebanese olive oil sector (insufficient agricultural knowledge, inadequate financial support, lack of horticultural and cultural practices, deficiency in marketing skills and product classification, etc.), Lebanese olive oil has been opening to the export market[2].

In olive oil-producing countries, there have been many exhaustive studies in the aim of characterization of the chemical composition of olive oil varieties or oil produced in a specific area and how it relates oil quality[6 - 9]. Other studies have been conducted to reveal how extraction systems affect the final olive oil quality [10 -14].

No previous scientific data has been provided to show the influence of extraction systems on the quality of *Baladi*olive oil in Lebanon. This paper examines the influence of (1) the extraction system and (2) the production area on the physicochemical properties of olive oil, during crop season 2013/2014.

2. Materials and Methods

2.1. Preparation of Olive Oil Samples

Samples of olive oil (n=25) were collected from industrial mills located in the districts of North Lebanon (Koura, Zgharta, Batroun, Danniyeh and Akkar) during crop season 2013/2014. The olives from which olive oil is extracted belong to "Soury", the common variety of olives cultivated in Lebanon. Eleven oils were extracted, using the triple-phase decanter, while fourteen were processed by the old traditional press technique. The oil samples were classified according to production area in five groups (Table 1). All samples were filtered through anhydrous Na_2SO_4 and stored at 4°C in the dark using 600 mL amber glass bottles without head space until analysis.

Table 1: Description of olive oil samples used in this study.

District	Sample code	Production area	Altitude (meters)[†]	Extraction System
Koura	KT kf	KfarAaqqa	360	Traditional press
	KT dc	Dar Chmizzine	390	Traditional press
	KT ko	Kousba	500	Traditional press
	KP da	Dar Baaechtar	380	Triple-phase decanter
	KP bz	Bziza	410	Triple-phase decanter
Zgharta	Z T kr	KfarDlaqous	326	Traditional press
	Z T rn	Rachaaine	245	Traditional press
	Z P ar	Aarjes	330	Triple-phase decanter
	Z P km	KarmSaddeh	600	Triple-phase decanter
	Z P bn	Bchannine	320	Triple-phase decanter
Batroun	B T ka	KfarAabida	200	Traditional press
	B T dk	Der Kfifane	440	Traditional press
	B T do1	Douma	2500	Traditional press
	B P do2	Douma	2500	Triple-phase decanter
	B P sh	Chibtine	500	Triple-phase decanter
Akkar	A T bo1	Baino	520	Traditional press
	A T bk1	Bqerzla	260	Traditional press
	A T bk2	Bqerzla	260	Traditional press

	A P ra	Rahbeh	560	Triple-phase decanter
	A P bo2	Baino	520	Triple-phase decanter
Danniyeh	D T kh1	KfarHabou	741	Traditional press
	D T mr	Markebta	220	Traditional press
	D T dr	DeirAammar	1050	Traditional press
	D P kh2	KfarHabou	741	Triple-phase decanter
	D P br	Borj El Yahoudiyi	190	Triple-phase decanter

†Altitudes were retrieved from www.localiban.org.

2.2. Analytical Methods

Free acidity, expressed as percentage of oleic acid (%), and peroxide value expressed as milli equivalents of active oxygen per kilogram of oil (meq O_2/kg) were measured using the analytical methods described in the European Union standard methods Regulations 2568/91 and the subsequent amendments [15]. Refractive index was determined using a pocket refractometer (ATAGO®,PAL).

Total carotenoids compounds were determined using Biochrom Libra S12 UV/Vis spectrophotometer, and expressed as mg of ß-carotene per Kilogram of oil [16].

Total phenols were extracted and determined in the methanolic extract according to the Folin-Ciocalteu colorimetric method. Results were expressed as mg of caffeic acid per Kilogram of oil [17]. Oxidative stability was evaluated by the Rancimat method[18].

For the determination of fatty acid composition, the methyl esters were prepared by vigorous shaking of a solution of oil in hexane (0.2 g in 3 mL) with 0.4 mL of 2N methanolic potash and analyzed by GC with an Agilent Technologies (HP5) chromatograph equipped with a FID detector. A fused silica column (30 m length x 0.25 mm i.d.) was used. Helium was employed as carrier gas with a flow through the column of 1 mL/min. The temperatures of the injector and detector were set at 240°C and the oven temperature was 210°C. The injection volume was 1µL [19].Peaks were identified by comparing their retention time with those of pure standards. All standards had a GC purity ≥ 95% and were purchased from Sigma–Aldrich (Germany).Results were displayed as percent of to talidentified FAs. All solvents used were of analytical grade. Every determination was carried out in triplicate.

2.3. Statistical Analysis

Statistical differences were estimated by the ANOVA test at the 5% significant level ($p<0.05$) for the evaluated parameters. When ANOVA indicated significant difference, a pair-wise comparison of means was done using Student t-test. Pearson's test was applied for correlation analysis.

3. Results

Table 2 shows the acidity values of the olive oil samples. The range of the acidity values was between 0.50 % of oleic acid for samples B P $do_2$and K P bz, and 2.88 % of oleic acid for sample Z T rn. The amount of free fatty acids is less than 1% of oleic acid (extra virgin olive oil) for all the samples extracted using the continuous 3-phase system except for one sample Z P km while less than half of the samples extracted using the discontinuous traditional system appeared to belong to the extra virgin olive oil category.

Table 2: Variations in physicochemical composition of olive oil samples (n=25) (mean values ± standard deviation*)

Sample	Acidity (% oleic acid)	Peroxide Index (meqO_2/kg)	Refractive Index (SD*<0.01)	Phenols (mg/kg)	Oxidative Stability (h) 100ºC	Oxidative Stability (h) 120ºC	Carotenoids (mg/kg)
KT kf	0.94±0.07	11.91±0.08	1.4676	209.1±0.05	14.76	2.83	2.2±0.2
KT dc	1.22±0.02	12.48±0.71	1.4679	339.6±0.07	24.59	4.29	1.9±0.4
KT ko	2.73±0.03	20.40±0.01	1.4684	136.0±0.03	9.14	1.69	1.9±0.3
KP da	0.58±0.00	9.99±0.72	1.4675	264.4±0.02	22.91	4.53	1.5±0.1
KP bz	0.50±0.05	9.47±0.67	1.4674	358.1±0.2	28.72	5.85	2.0±0.0
Z T kr	0.97±0.03	9.92±0.03	1.4675	144.4±0.02	18.48	3.22	1.3±0.2
Z T rn	2.88±0.04	18.93±1.40	1.4683	123.9±0.00	8.69	1.90	2.3±0.5
Z P ar	0.87±0.03	7.95±0.04	1.4675	278.1±0.02	28.72	6.75	2.3±0.4
Z P km	1.71±0.03	13.98±0.08	1.4679	200.7±0.04	20.75	5.20	1.2±0.1
Z P bn	0.52±0.02	5.74±0.35	1.4673	144.9±0.03	15.66	4.07	1.2±0.1

B T ka	1.09±0.03	11.97±0.01	1.4678	156.5±0.04	17.12	3.58	1.2±0.3
B T dk	0.63±0.03	9.98±0.01	1.4676	123.9±0.00	10.32	1.43	1.3±0.6
B T do1	0.54±0.01	5.99±0.00	1.4674	238.1±0.02	34.59	5.39	2.3±0.5
B P do2	0.50±0.00	5.29±0.16	1.4672	166.0±0.02	25.82	3.34	1.1±0.2
B P sh	0.92±0.04	11.46±0.66	1.4676	264.4±0.03	22.83	3.21	1.3±0.5
D T kh1	1.57±0.00	7.96±0.01	1.4678	188.6±0.02	18.2	3.37	1.0±0.2
D T mr	2.80±0.07	26.22±0.72	1.4684	94.9 ±0.04	9.32	1.89	1.1±0.3
D T dr	1.48±0.03	9.95±0.03	1.4679	328.1±0.01	24.88	4.99	0.6±0.3
D P kh2	0.86±0.04	7.96±0.03	1.4676	221.7±0.09	26.88	4.63	1.1±0.0
D P br	0.92±0.03	7.95±0.00	1.4675	184.4±0.04	15.94	2.99	0.9±0.1
A T bo1	1.97±0.02	26.36±0.84	1.4685	75.4 ±0.02	6.34	1.07	1.6±0.4
A T bk1	0.51±0.00	5.05±0.03	1.4673	326.0±0.01	25.07	4.56	1.3±0.2
A T bk2	0.52±0.01	5.97±0.00	1.4673	162.8±0.03	19.73	3.80	1.3±0.0
A P ra	0.81±0.03	7.44±0.69	1.4676	80.2±0.02	29.21	5.85	1.1±0.03
A P bo2	0.56±0.00	5.54±0.58	1.4674	204.9±0.00	31.49	6.18	2.1±0.1

*SD: Standard Deviation.

The range of the peroxide index values was between 5.05 meqO2/kg for sample A T bk_1 and 26.36 meqO2/kg for sample A T bo_1. As shown in Table 2, the peroxide index was less than 20 meqO_2/Kg (extra virgin olive oil) for all the samples extracted using the continuous 3-phase system while not all the samples extracted using the discontinuous traditional system appeared to belong to the extra virgin olive oil category.

The range of the refractive index values vary between 1.4672 for sample B P do_2 and 1.4685 for sample A T bo_1. The refractive index was less than 1.677 (extra virgin olive oil) for all the samples extracted using the continuous 3-phase system except for one samples while less than half of the samples extracted using the discontinuous traditional system appeared to belong to the extra virgin olive oil category.

The highest total phenolic content was found equal to 358.1 mg/kg for sample K P bz while sample A T bo1 showed the lowest total phenolic content at 75.4 mg/kg.

As for the oxidative stabilities, after being measured at 100°C and 120°C, the shelf lives of every sample could be predicted in years. At 100°C and 120°C, B T do1 lasted the longest (34.59 hrsand 6.75 hrs respectively) and A T bo1 lasted the least (6.34 hrs and 1.07 hrs respectively).

The concentrations of carotenoids ranged between 0.6 mg/kg for sample D T dr and 2.3 mg/kg for samples Z T rn and Z P ar.

Table 3: Fatty acid composition (% of fatty acid methyl esters) of olive oil samples obtained (n=25), (SD<0.1)[1]

Sample	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	SFA	MUFA	PUFA	C18:1/C18:2	MUFA/PUFA
K T kf	14.3	0.3	3.8	70.2	11.2	0.3	18.1	70.4	11.5	6.3	6.1
K T dc	13.7	0.3	3.9	69.7	12.2	0.3	17.6	69.9	12.5	5.7	5.6
K T ko	14.4	0.2	3.9	67.9	13.3	0.3	18.3	68.1	13.6	5.1	5.0
K P da	13	0.3	3.8	71.5	11	0.3	16.8	71.8	11.3	6.5	6.3
K P bz	13.4	0.3	4	69.2	12.8	0.3	17.4	69.5	13.1	5.4	5.3
Z T kr	14.6	0.2	3.7	68.3	12.8	0.3	18.4	68.5	13.1	5.3	5.2
Z T rn	15.8	0.2	3.3	66.2	14.1	0.3	19.2	66.4	14.4	4.7	4.6
Z P ar	14.4	0.2	3.9	67.9	13.3	0.3	18.3	68.1	13.6	5.1	5.0
Z P km	13.6	0.3	4.1	68.6	13.1	0.3	17.7	68.9	13.5	5.2	5.1
Z P bn	13.5	0.2	3.4	72.4	10.2	0.3	16.8	72.7	10.5	7.1	6.9
B T ka	13.9	0.2	3.6	63.4	12.2	0.3	17.4	63.6	12.4	5.2	5.1
B T dk	13.3	0.2	4	69.8	12.4	0.3	17.3	70	12.7	5.6	5.5
B T do1	11.3	0.2	3.5	74.9	9.8	0.3	14.8	75.1	10.1	7.7	7.4
B P do2	10.1	0.2	3.9	75.6	9.8	0.3	14	75.8	10.2	7.7	7.5
B P sh	14.8	0.3	4.5	82.8	13.6	0.3	19.3	83.1	13.9	6.1	6.0
D T kh1	14.2	0.2	3.5	69.1	12.8	0.3	17.6	69.3	13.1	5.4	5.3
D T mr	14.1	0.2	3.9	67.2	14.2	0.3	18	67.4	14.6	4.7	4.6
D T dr	15.3	0.2	3.9	66.5	13.8	0.3	19.2	66.7	14.1	4.8	4.7
D P kh2	12.2	0.2	4	72.4	10.9	0.3	16.2	72.6	11.2	6.7	6.5

D P br	15	0.2	3.9	67.4	13	0.5	18.9	67.6	13.5	5.2	5.0
A T bo1	12.4	1.6	3.6	71.5	10.6	0.4	16	73.1	10.9	6.8	6.7
A T bk1	13.6	0.2	3.6	72.6	9.6	0.3	17.2	72.8	9.9	7.5	7.3
A T bk2	12.6	0.2	3.7	73.3	10	0.3	16.2	73.5	10.3	7.4	7.2
A P ra	14.4	0	2.5	73.7	8.5	1	16.9	73.7	9.5	8.7	7.8
A P bo2	11.9	0.2	3.7	67.4	8.9	0.3	15.6	67.6	9.2	7.5	7.3
Codex Limits	7.5-20	0.3-3.5	0.5-5	55-83	3.5-21	≤1					

C16:0, Palmitic; C16:1, Palmitoleic; C18:0, Stearic; C18:1, Oleic; C18:2, Linoleic; C18:3, Linolenic acids

SFA, Saturated Fatty Acid; MUFA, Monounsaturated Fatty Acid; PUFA, Polyunsaturated Fatty Acid**.**

[1]Results are expressed as the mean of three independent determinations with the standard deviation.

Table 3 shows the fatty acid profile of extracted olive oil samples. The fatty acids identified were palmitic (C16:0), palmitoleic (C16:1n-7), stearic (C18:0), oleic (C18:1n-9), linoleic (C18:2n-6), and linolenic (C18:3n-3). The three major fatty acids were palmitic, oleic, and linoleic. Palmitic fatty acids ranged between 10.1% for B P do2 and 15.8% for Z T rn. Oleic fatty acids ranged from 63.4% for B T ka to 82.8% for B P sh. Linoleic acids range was between 8.5% for A P ra and 14.2% D T mr. Oleic on linoleic ratios ranged from 4.7 to 8.7 and MUFA on PUFA ratios ranged from 4.6 to 7.8. Most of the fatty acids composition variation covered the CODEX limits for virgin olive oil. Palmitoleic acid was detected at very low percentages; some below the CODEX limits (0.2%). However, the most noticeable divergence from the limits was for the Akkar district sample A P ra where no palmitoleic acid was detected and the Linolenic acid was detected at its maximum acceptable level, 1%. Tables 4 and 5 show the effect of the extraction system and the production area on the means of the physicochemical parameters in the olive oil samples.

Table 4: Comparison of means of the physicochemical quality parameters evaluated in the olive oil samples (effect of extraction system).

	Extraction system	
	Traditional*	**Centrifugation** (Three-Phase)**
Acidity (% oleic acid)	1.41 [a]	0.79 [b]
Peroxide Index (meqO2/kg)	13.08 [a]	8.61 [b]
Refractive Index	1.4678 [a]	1.4675 [b]
Phenols (mg/kg)	189.1 [a]	215.2 [a]
Oxidative Stability (hr)	17.2 [a]	24.4 [b]
Carotenoids (mg/kg)	1.5 [a]	1.4 [a]
Palmitic, $C_{16:0}$	13.8 [a]	13.3 [a]
Palmitoleic, $C_{16:1}$	0.3 [a]	0.2 [a]
Stearic, $C_{18:0}$	3.7 [a]	3.8 [a]
Oleic, $C_{18:1}$	69.3 [a]	71.7 [a]
Linoleic, $C_{18:2}$	12.1 [a]	11.4 [a]
Linolenic, $C_{18:3}$	0.3 [a]	0.4 [a]
SFA	17.5 [a]	17.1 [a]
MUFA	69.6 [a]	71.9 [a]
PUFA	12.4 [a]	11.8 [a]
Oleic/Linoleic	5.9 [a]	6.5 [a]
MUFA/PUFA	5.7 [a]	6.2 [a]

*Mean values of olive oil parameters extracted using the traditional pressing.

**Mean values of olive oil parameters extracted using centrifugation.

[a,b]Means of pairs in the same row with different superscript are significantly different ($P < 0.05$).

Table 5: Comparison of means of the physicochemical quality parameters evaluated in the olive oil samples (effect of production area).

	Production Area				
	Koura	**Zgharta**	**Batroun**	**Danniyeh**	**Akkar**
Acidity (% oleic acid)	1.19 [a]	1.39 [a]	0.73 [a]	0.87 [a]	1.52 [a]
Peroxide Index (meqO2/kg)	12.85 [a]	11.29 [a]	8.94 [a]	10.07 [a]	12.41 [a]
Refractive Index	1.4677 [a]	1.4677 [a]	1.4675 [a]	1.4676 [a]	1.4678 [a]
Phenols (mg/kg)	261.4 [a]	178.4 [a]	189.7 [a]	203.5 [a]	169.9 [a]
Oxidative Stability (hr)	20.0 [a]	18.5 [a]	22.1 [a]	19.0 [a]	22.4 [a]
Carotenoids (mg/kg)	1.9 [a]	1.7 [a,b]	1.5 [a]	1.0 [c]	1.5 [b]
Palmitic, $C_{16:0}$	13.8 [a]	14.4 [a]	12.6 [a]	14.2 [a]	13.0 [a]
Palmitoleic, $C_{16:1}$	0.3 [a]	0.2 [a]	0.2 [a]	0.2 [a]	0.4 [a]
Stearic, $C_{18:0}$	3.9 [a]	3.7 [a]	3.9 [a]	3.8 [a]	3.4 [a]
Oleic, $C_{18:1}$	69.7 [a]	68.7 [a]	73.3 [a]	68.5 [a]	71.7 [a]
Linoleic, $C_{18:2}$	12.1 [a]	12.7 [a]	11.6 [a]	12.9 [a]	9.5 [b]
Linolenic, $C_{18:3}$	0.3 [a]	0.3 [a]	0.3 [a]	0.3 [a]	0.5 [a]
SFA	17.7 [a]	18.1 [a]	16.6 [a]	18.0 [a]	16.4 [a]
MUFA	69.9 [a]	68.9 [a]	73.5 [a]	68.7 [a]	72.1 [a]
PUFA	12.4 [a]	13.0 [a]	11.9 [a]	13.3 [a]	10.0 [b]
Oleic/Linoleic	5.8 [a]	5.5 [a]	6.5 [a,b]	5.4 [a]	7.6 [b]
MUFA/PUFA	5.7 [a]	5.4 [a]	6.3 [a,b]	5.2 [a]	7.2 [b]

[a,b]Means of pairs in the same row with different superscript are significantly different ($P < 0.05$).

4. Discussion

Statistically significant differences ($p<0.05$) were found for acidity, peroxide index and absorption (270 nm) among the extraction systems with no significant differences($p>0.05$) among the production area. The same findings were observed by several authors [14, 20]. As could be expected, the acidity appeared to be higher when pressure is used to extract olive oil. This is linked to the fact that in the traditional press, the H_2O and the olive oil are separated together from the solid extract and are left together till the decantation step takes place. The time that the olive oil stays in contact with the water until separation occurs will cause the breakdown of triglycerides releasing high concentrations of free fatty acids [14, 16].

The peroxide index values indicate that olive oils have undergone primary oxidation.Our results are to those observed by other authors where the peroxide index is higher when extracted using the traditional discontinuous system[14, 20]. It is clear that the agitation of olives using a millstone for a certain time subjects the paste to the air. Thus in this step, the olive oil will be subjected to both light and oxygen which will cause lipid peroxidation [21].

It is important to point out that levels of refractive index indicate if the olive oil has undergone any adulteration. A relation exists between the refractive index and the iodine value which increases with increasing unsaturation. In other words, the peroxide index and the refractive index increase together in olive oil [22]. Another relation is found between the acidity and the refractive index for as the acidity of the olive oil increase, the refractive index will also increase [23].

No statistically significant differences ($p>0.05$) were observed for total carotenoids levels among extraction systems. The extraction systems do not affect the carotenoids levels because they are lipid soluble and thus less affected by the different amounts of water added during the various olive oil processing methods [24]. Examination of the data revealed that total carotenoids showed statistically significant differences among the different production areas ($p<0.05$) and that carotenoid levels varied with the production area[25]. These variations could be related to different climatic temperatures, altitudes and possibly different irrigation regimes applied in each production area [25, 26].

In our study, total phenols revealed no statistically significant differences among production areas ($p>0.05$) and extraction systems ($p>0.05$). Some authors have noticed close findings [13, 14]. However, other authors have found that total phenols have significantly differed among various extraction systems. It is important to point out that olive oil phenols were not solely affected by the extraction systems; other olive oil processing factors have been shown to influence phenols levels. These factors could have produced an effect on the phenols more evident than the extraction system's effect thus masking the extraction system's effect. Such factors include the crushing machine used, the velocity of the crushing machine, malaxation time and temperature, volume of water added and the duration of contact with water. The aforementioned variables affecting phenols levels have been reported in many previous studies [27, 28].

None of the fatty acids detected have revealed any significant difference between the traditional and the centrifugation extraction systems ($p>0.05$). Linoleic acid, PUFAs, oleic to linoleic and MUFA to PUFA ratios presented statistically significant differences among production areas ($p<0.05$). Spanish and Turkish studies respectively, showed significant differences between all fatty acids in different areas [13, 26], unlike a Palestinian study which showed significant differences between few fatty acids [29]. Our results were very close tothe results obtained in the latter study [29], which is probably due to the fact that Lebanon and Palestine are neighboring geographical regions. The main fatty acids differences between areas have been attributed to altitude and climate temperature of the region. In the case of our study, results showed a strong negative correlation between altitude and palmitic acid ($r = - 0.65$) as well as between altitude and saturated fatty acids ($r = -0.63$). In fact, the samples from Batroun region which encompass a local area of the highest altitude (2500m) showed the lowest palmitic acid compositions (12.6%), the second lowest saturated fatty acids (16.6%), the highest oleic acid percentage (73.3%) and the second highest MUFA/PUFA ratio (6.3).These results are consistent with studies which revealed that olive trees grown at lower altitudes produced higher saturated fatty acids (SFA) [30] and with studies which revealed that highest altitudes produced oil with lowest palmitic acid and highest oleic acid composition and vice versa [29]. Cooler areas produced oils with higher unsaturated fatty acids [31]. Considering that high altitudes provide cooler climatic temperatures, then high altitudes would produce high unsaturated fatty acids, thus confirming with our oleic acid and MUFA/PUFA ratio discussed previously. However, contradictory results have been reported in previous studies, which revealed that high altitudes produced oils with high saturated fatty acids and low levels of unsaturated fatty acids confirming with the "Ivanov" rule stating that the amount of linoleic acid rises when the temperature decreases, contrary to oleic acid[25].

Oxidative stability showed no statistically significant differences among production areas ($p>0.05$). However, traditionally pressed oils and centrifuged oils' stabilities differed significantly with centrifuged oils presenting higher oxidative stabilities. Olive oils have been known to be highly resistant to oxidation due their natural antioxidants such as phenols and lower fatty acid unsaturation levels [14]. In fact, a strong positive correlation has been established between phenols and oxidative stability ($r = -0.61$). Similar results have been reported by many previous studies [13, 31, 32]. In addition, the higher the oleic acid to linoleic acid and MUFA to PUFA ratios, the more stable the oil is because polyunsaturated acids are more prone to oxidation due to their higher number of double bounds. This has been revealed through a positive correlation has between the oxidative stability and oleic to linoleic ratio ($r = 0.47$) and between the oxidative stability and MUFA to PUFA ratio ($r = 0.46$). Also, polyunsaturated fatty acids have presented a negative correlation ($r = -0.43$) with the oxidative stability revealing how these acids are more prone to oxidation and thus decrease the oil's stability as they increase.

5. Conclusion

This study was conducted with the aim of studying the influence of the extraction system and the production area on the physicochemical parameters of *Baladi* olive oil. The above results showed that the olive growing area influenced olive oil fatty acid profiles and carotenoid levels. High altitudes produced oils with low saturated fatty acids and high unsaturated fatty acids. Extraction systems affected the oxidative stability, acidity, peroxide index, and the refractive index. Thus, future related studies are needed to further confirm the Lebanese olive oil characterization. Also, our sample size was relatively small. Therefore, our findings require more investigation with larger sample sizes. Olive oils will need to be subjected to more exhaustive controls. This preliminary study can surely be improved by considering the analysis of chlorophyll and carotenoid ratio content, the profile of phenolic compounds, and the oxidative stability before and after extracting phenols.

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7. References

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