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Chemical and Sensorial Characteristics of Olive Oil Produced from the Lebanese Olive Variety 'Baladi'

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Abstract: The olive oil quality, nutritional and sensorial characteristics are associated with the chemical composition, which is the result of a complex interaction between several environmental, agronomical and technological factors. The aim of the present study is to investigate the impact of the geographical origin, harvesting time and processing system on the chemical composition and sensorial characteristics of olive oils produced from the Lebanese olive 'Baladi'. Samples (n = 108) were collected from North and South Lebanon, at three different harvesting times and from four processing systems. Results showed a strong effect of origin, processing system and harvest time on oil quality, fatty acid composition, total phenols and OSI. The early harvest showed higher total phenols content (220.02 mg GAE/Kg) and higher OSI (9.19 h). Moreover, samples obtained from sinolea and 3-phases recorded the lowest free acidity (0.36% and 0.64%), and the highest OSI (9.87 and 9.84 h). Consumers were not unanimous regarding the studied factors, although samples recording high ranks were mostly from South using sinolea, 3-phases and press systems at early and intermediate harvest. The overall findings suggest that the selection of the harvesting time and of the processing system could have significant influence on the characteristics of the olive oil.

Keywords: *Olea europaea* L.; olive oil; geographical origin; processing system; harvesting time; olive oil quality; fatty acid composition; sensorial evaluation; consumer preferences

1. Introduction

Olive oil is the most commonly consumed vegetable oil in the Mediterranean area owing to its sensorial quality and beneficial health effects [1–3]. The health promoting properties and overall taste of olive oils are associated in particular with their chemical composition [3]. While the product chemical and sensory characteristics determine its quality, they are the result of a complex interaction between several environmental, agronomical and technological factors. In particular, the geographical origin, the olive variety, the harvesting time and the processing system represent the most important factors influencing the olive oil composition [4–7]. Previous studies showed different fatty acid, sterol and tocopherol profiles for the same varieties cultivated in different regions [8]. Studies also reported that the phenolic and chlorophyll contents decrease along ripening with the parallel decrease of

the bitter and pungent tastes and increase of the sweetness [9]. Other authors reported an increase in total and individual phenols with the increase of ripening index between 2 and 3.5 after which they decrease dramatically [10,11]. The fatty acid composition also varies during ripening where palmitic acid (C16:0) decreases, linoleic acid (C18:2) increases and oleic acid (C18:1) remains constant. This results in a decrease in monounsaturated (MUFA) to polyunsaturated fatty acids (PUFA) and saturated to unsaturated fatty acid ratio, leading to lower oil oxidative stability and loss of oil quality in general [12,13]. The selection of the processing systems could have a significant effect on the oil oxidation due to the exposure to air oxygen in the press and sinolea systems and the use of mats in the press system. These inconveniences in the aforementioned systems were completely overcome in the modern systems including the 2- and 3-phases [14,15]. However, the 3-phases system might result in a decrease in the phenolic and aromatic compounds leading to lower oxidative stability due to the use of water that could dissolve the hydrophilic phenols that will be removed with the olive mill waste water [16].

In Lebanon, olive oil production holds a very important status in the country's economy. The national production is increasing and has reached 23,000 tons in 2017. Actually, Lebanon counts as an actor in the international trade of olive oil with more than 7703 tons of exports oriented towards countries where a large Lebanese diaspora lives such as United States, Canada, and gulf countries among others [17]. Olive production mainly occurs in the North (41%) and the South-Nabatiye (36%) [17]. Among all, 'Baladi' (that means local or autochthonous in Arabic language) is the most cultivated variety for its adaptation to the local climatic conditions and for its double use value [18–22]. 'Baladi', also known in many regions as 'Soury' (according to the Lebanese town of Tyre that means in Arabic language Sour), is characterized by a medium to high oil content (around 28% expressed on fresh weight basis) and has a low pulp to pit ratio. This variety is highly productive although it has a slight alternate behavior and is highly susceptible to the olive fruit fly (*Bactorcera oleae*) and to the olive wilt disease (*Verticillium dahlia*).

In Lebanon, studies have mainly tackled the ecological characterization of some ancient olive trees in the Bshaale area and their age estimation [23]; or, the influence of the processing system and the production area on the physicochemical properties of 25 olive oil samples collected during crop season 2013/2014 [24]. Also, El Riachy et al. [25] investigated the effect of different irrigation regimes on fresh fruit weight, oil yield, quality and composition of olive oil from Baladi and Edelbi varieties. Chehade et al. [26] evaluated the impact of the cultivation area and the harvesting time on the fruit and oil characteristics of the main Lebanese olive varieties. Despite the importance of the olive oil sector in Lebanon and the increased interest in sensorial and beneficial effects of olive oil, there is a lack of data elucidating the combined effect of agro-industrial factors on the olive oil characteristics produced in this country. For this reason, the objective of the present study is to assess the effects of the geographical origin, the harvesting time and the processing system on the chemical composition of olive oil and on consumer preferences.

2. Materials and Methods

2.1. Experimental Sites

This study was implemented in 4 of the most important olive growing regions of Lebanon: Akkar and Zgharta-Koura district in the North governorate of Lebanon, Hasbaya in Nabatiye governorate (South Lebanon) and Jezzine in South Lebanon governorate (Figure 1). Akkar district is characterized by the presence of a relatively large coastal plain with high mountains to the east. Zgharta and Koura are districts that stretch from the Mediterranean Sea up to Mount Lebanon and comprise a series of foothills surrounding a low-lying plain where olive is cultivated. Hasbaya district is characterized by a long fertile valley lying at the western foot of Mount Hermon overlooking a deep amphitheater from which a brook flows to the Hasbani. Finally, the olive lots from Jezzine district originated from villages extended at altitudes from 200 to 1000 m all facing the Mediterranean Sea.

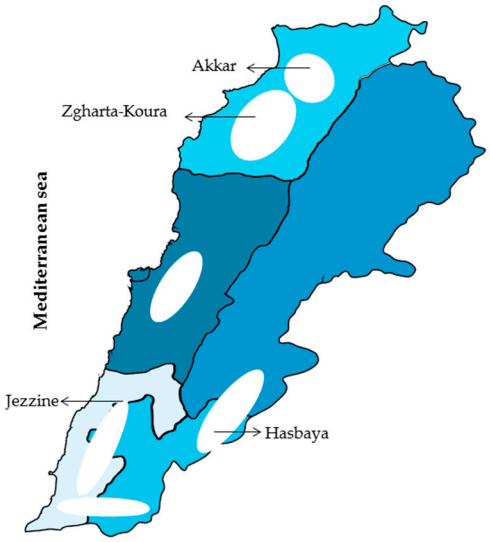

Figure 1. Map of olive groves in Lebanon indicating the sites where olives were collected. The white shapes in the map indicate the most important olive growing regions in the country [27].

2.2. Olive Fruits and Olive Oil Sampling

Samples of olive fruits and olive oils from the 'Baladi' variety were collected from the most common olive mills in the 4 olive growing regions, as follows: Press, 2- and 3-phases in Akkar and Jezzine; press, 3-phases and sinolea in Hasbaya; and, press and 3-phases in Zgharta-Koura.

The samples were collected at three harvesting times: early harvest (at the beginning of harvesting season in each region), intermediate harvest (at the middle of season) and late harvest (at the end of harvest). At each time three olive samples and three olive oil samples were collected from each region and from each processing system, except in the 2-phases system in Akkar region where 6 olive samples and 6 olive oil samples were collected (Table 1).

Table 1. Sample characteristics of olive fruits and olive oil from different geographical origins and different processing systems. The rainfall corresponds to mean values collected between 2009 and 2015 from climatic stations of the Lebanese Agricultural Research Institute (LARI).

Region	Rainfall	Altitude	Latitude	Longitude	Processing System	Olive Fruits	Olive Oil
Akkar	850 mm	300–700 m	34.5506°	36.0781°	Press 2-phases 3-phases	9 18 9	9 18 9
Zgharta-Koura	800 mm	200–350 m	34.2689°	35.7929°	Press 3-phases	9 9	9 9
Hasbaya	650 mm	650–1050 m	33.3833°	35.6833°	Press Sinolea 3-phases	9 9 9	9 9 9
Jezzine	750 mm	200–1000 m	33.5408°	35.5862°	Press 2-phases 3-phases	9 9 9	9 9 9
Total number of samples						108	108

2.2.1. Olive Fruits Samples

From each olive lot belonging to one farmer, a sample of 100 olive fruits randomly selected was taken for the determination of the ripening index (RI), as described by Frías et al. [28]. Briefly, the selected fruits were classified according to their skin color into the following 5 groups: 0 = the skin is green; 1 = the skin is yellow or yellowish-green color; 2 = the skin is a yellowish color with reddish

spots; 3 = the skin is a reddish or light violet color; and, 4 = the skin is black. Then, the total number of olives in each group (n_0; n_1; .... n_4) was recorded, and the following equation was applied to determine the RI:

$$RI = \frac{[(0 \times n_0) + (1 \times n_1) + (2 \times n_2) + (3 \times n_3) + (4 \times n_4)]}{100} \quad (1)$$

2.2.2. Olive Oil Processing

The olive lots were processed to obtain the olive oil using the four following systems:

1. Press system: In this system, the olives fruits were crushed using a hummer mill that leads to a more complete breakage of olive flesh. Then, the crushed olives were grinded for around 30 min using cylindrical millstones to obtain the olive paste. The obtained olive paste was then placed on mats, stacked one above the other and pressed using a hydraulic press at a pressure up to 400 atm. The obtained oil was then pumped to a vertical centrifuge to separate the oil from vegetable water and other impurities.
2. Sinolea system (also known as cold percolation system): In this system, the olive fruits were crushed in a hammer mill. Then, the oil was separated from the olive paste using the sinolea system consisting of a series of metal discs used to mix the paste inside a perforated semi cylindrical vat including rows of metal discs or plates that dip into the paste, and the oil wets and sticks to the metal and is removed with scrapers in a continuous process. The oil dropping down the vat by gravity was collected in stainless steel recipients. To increase the efficiency of oil extraction of this system it was combined to 3-phases decanters. The oil obtained was mixed to the previously collected oil, and then separated from any remaining impurities by a vertical centrifuge.
3. 3-phases system: The olive fruits were crushed also by using a hammer mill, and then they were slowly mixed in a malaxation machine at 25 to 28 °C in order to coalesce the small oil droplets. At the end of this process, the resulting paste was homogenous with large oil spots floating on the surface and ready for separation inside the decanter. The decanter was a horizontal centrifuge rotating at around 3000 rpm to achieve the separation of the constituents of the homogenous paste into 3 different products: (i) dry pomace; (ii) vegetable water; and (iii) oil with small quantities of vegetable water that were removed by vertical centrifugation. In order to achieve better separation of the three phases in the decanter, 200–300 L of water per tons of olive paste were added.
4. 2-phases system: The 2-phases processing system was quite similar to the 3-phases system. However, the main difference is that the decanter separated the homogenous paste into only two phases: The first one is the mixture of pomace and vegetable water (wet pomace) and the second one is the oil mixed with small quantities of vegetable water. The obtained oil underwent a vertical centrifugation to clean it. In this system, no water was added to the paste.

2.3. Olive Oil Chemical Analysis

2.3.1. Free Acidity, Peroxide Values and UV Absorption

Free acidity, peroxide value, K232 and K270 (UV absorbance at 232 nm and 270 nm) were determined according to the procedures described in the Commission Regulation (EEC) No. 2568/91 [29].

2.3.2. Fatty Acids Composition

Fatty acids were determined as fatty acid methyl esters (FAMEs) according to the method described by IOC [30]. In brief, 0.1 g of oil were vigorously mixed with 2 mL of *n*-hexane and 200 μL of a methanolic solution of KOH (2 M), for 1 min. The mixture was allowed to set for 5 min,

and the upper phase was placed in a GC vial before injection, in duplicate, into a Shimadzu GC-2010 Plus (Tokyo, Japan) coupled to a flame ionization detector (FID) (280 °C). The used column was a fused silica capillary column (DB-wax, Agilent Technologies, Wilmington, DE) with 30 m length × 0.25 mm i.d. and 0.25 µm of film thickness. The nitrogen gas was used as carrier gas with a flow of 1.69 mL/min. Regarding the injector, the temperature was kept at 250 °C and a split ratio of 1:50 was used. A gradient oven temperature program was adopted with initial temperature set at 165 °C for 15 min, then temperature raised from 165 °C to 200 °C at a rate of 5 °C/min, and held at 200 °C for 2 min, then increased from 200 °C to 240 °C at a rate of 5 °C/min, and finally kept at 240 °C for 5 min. Authentic commercial standards were used to identify each FAME and the concentration was calculated as percentage of total peaks areas.

2.3.3. Extraction of Phenolic Compounds and Determination of Total Phenolic Content (TPC)

During prior analyses, samples were let to thaw at room temperature. The phenolic compounds in were extracted using a modification of the procedure described by Montedoro et al. [31]. An aliquot of 3 g oil was added to 2 mL of hexane in a flask and shaken for 15 s. Volumes of 1.75 mL of methanol/water (60/40, *v*/*v*) and 250 µL of syringic acid solution (60 ppm, internal standard) were added to the mixture and shaken for 2 min to undergo the first extraction. For the second extraction, 2 mL of methanol/water (60/40) were added and shaken for 2 min. The first and the second extracts were combined. The extracts were stored at −20 °C for further analysis.

TPC was determined spectrophotometrically using the Folin-Ciocalteu method [32]. A solution of 20 g Na_2CO_3 in 80 mL of distilled water and a solution of 100 mg of gallic acid in 100 mL methanol/water (60/40 *v*/*v*) were prepared. The TPC was determined precisely by introducing an aliquot of 20 µL of the methanol-water extract in an Eppendorf vial with 1.58 mL of deionized water, 300 µL of 20% Na_2CO_3 and 100 µL of Folin-Ciocalteu reagent. The mixture was manually shacked and placed in an oven at 50 °C for 5 min to accelerate the reaction, and then set to rest for 30 min at room temperature. Similarly to the samples, blank and calibration solutions of gallic acid were prepared. Then, the absorbance at 765 nm was measured using a Jenway UV/Vis spectrophotometer (Staffordshire, ST15 OSA, UK) and the TPC was expressed as mg gallic acid equivalent (GAE) per kg of oil.

2.3.4. Oxidative Stability Index (OSI)

OSI (h) was determined using a Rancimat apparatus (Model 892 Professional Rancimat, Metrohm SA, Herisau, Switzerland) according to the method described by Tura et al. [33]. This method consists of increasing the oxidation reactions by keeping 3 g of oil at 120 °C under a constant air flow of 20 L/h; and then, determining the conductivity variation of water (60 mL) due to the increase in oxidative compounds.

2.4. Consumer Preferences

2.4.1. Olive Oil Samples

The distinction of the olive oil samples determining if they are defected or without defects and the intensity of fruity, bitter and pungent sensory descriptors were evaluated only on the olive oil samples that showed chemical analyses results within the norms of extra virgin olive oil published in EEC [29]. Thus, a total of 50 olive oil samples from 108 olive oil samples (46.30%) were tested. The oil samples were geographically distributed as follows: 13 oil samples originated from Akkar, 22 from Hasbaya, 6 from Jezzine, and, 9 from Zgharta-Koura. Among the samples, 15 were processed by press system, 8 by sinolea, 5 by 2-phases and 22 by 3-phases system; from which, 22 oil samples correspond to the first harvest, 15 to the second harvest and 13 to the third one. These samples were stored for in dark, at −20 °C for a duration of 4 months and thawed to reach room temperature before tasting.

During the sessions, the samples were served in plastic cups; and a volume of approximately 10 mL was randomly served for each person with no obligation to finish the cup.

2.4.2. Sensory Characteristics

Sensory characteristics were evaluated by consumer preference test and an experienced sensorial panel.

Consumer Preference

A total of 188 consumers participated to the consumer preferences sessions. Among consumers 56.9% were females; and, 46.8% were between 19 and 30 years old and 53.2% were more than 30 years old. For each sample, consumers had to judge a sample using 'I like' or 'I don't like'. A maximum of 7 samples was given per person and session.

Experienced Sensorial Panel

The sensory analyses were also performed by a fully trained analytical sensorial panel composed of 5 trained assessors to perform olive oil sensorial analysis. Each taster first smelled the oil and judged it as defected or without defects. Then, the panel members tasted the oils without defects and marked the intensity of fruity, bitter and pungent attributes. Attributes were assessed on an oriented 10 cm line scale and quantified measuring the location of the mark from the origin according to the method of organoleptic characterization of virgin olive oil described by the IOC [34]. This method was used to classify each oil according to the intensity of the three mentioned positive attributes. An attribute was considered as delicate if the median is lower than 3; as medium if the median is between 3 and 6; and, as robust if the median is higher than 6.

2.5. Statistical Analysis

Acidity, peroxide value and UV absorbance were performed in Triplicate; and, the fatty acid composition and the OSI were done only in duplicate; however, the Folin Ciocalteu assay was performed only once. The obtained data were subjected to a multivariate analysis of variance (MANOVA) and to one-way ANOVA. Concerning the consumer preferences and the sensory profile, the collected data were analyzed using the Friedman's non-parametric test. To ensure the validity of the results, all assumptions required for the mentioned tests were checked before running them. A result is considered as statistically significant for a p-value less than 0.05. Note that, for multiple comparisons the p-value levels were adjusted using Bonferroni corrections which consist of dividing the α value (0.05) by the number of comparisons. Mean comparison (Duncan test, at $p < 0.05$) and different charts showing the interactions between regions, harvesting times and processing systems were elaborated by using the statistical package 'IBM-SPSS (version 22.0, IBM, Rochester, NY, USA).

3. Results and Discussion

3.1. Ripening Index (RI)

The difference in ripening between the olives lots processed at each harvesting time was investigated. The results showed that RI was very highly significantly different among the different harvesting times ($p < 0.001$). This difference was explained by a high eta square (70.9%). Mean comparisons showed a wide range of variation between the three harvesting times with mean values significantly increasing from early harvest (RI = 1.35) to intermediate harvest (RI = 2.34) and to late harvest (RI = 3.43). These results are in agreement with those obtained by El Riachy et al. [35] in a study on 3 varieties ('Arbequina', 'Picual' and 'Frontoio') and 12 of their segregating populations; where the RI was correlated with the harvesting time, although the evolution of ripening was different between varieties.

3.2. Oil Quality Parameters

The effects of geographical origin, processing system and harvesting time on the quality indices of olive oil including free acidity, peroxide value, K232 and K270, were investigated. Results (Table 2) showed a very highly significant effect of the interactions geographical origin * processing system * harvesting time, geographical origin * processing system and geographical origin * harvesting time on this set of variables ($p < 0.001$). Moreover, processing system * harvesting time revealed a significant effect on these quality indices ($p < 0.05$). As per each single factor, the geographical origin and the processing system showed a very highly significant effect ($p < 0.001$) and the harvesting time had a significant effect on this set of variables ($p < 0.05$).

Table 2. Results of the Multivariate Analysis of Variance (MANOVA) of the two sets of variables: quality parameters and fatty acid composition.

Parameters	Factors	Wilk's Λ	F	Partial η^2	Power
Quality parameters	Geographical origin (A)	0.35	7.83 ***	0.30	1.00
	Processing system (B)	0.55	4.01 ***	0.18	1.00
	Harvesting time (C)	0.76	2.63 *	0.13	0.92
	A * B	0.45	4.09 ***	0.18	1.00
	A * C	0.46	2.59 ***	0.18	1.00
	B * C	0.57	1.86 * [2]	0.13	0.97
	A * B * C	0.33	2.94 *** [1]	0.24	1.00
Fatty acids composition	Geographical origin (A)	0.27	8.05 ***	0.36	1.00
	Processing system (B)	0.82	1.00	0.07	0.59
	Harvesting time (C)	0.40	8.20 ***	0.37	1.00
	A * B	0.31	5.00 ***	0.25	1.00
	A * C	0.60	1.29	0.10	0.87
	B * C	0.44	2.17 **	0.15	0.99
	A * B * C	0.44	1.64 ** [3]	0.15	0.99

[1] *** $p < 0.001$; [2] * $p < 0.05$; [3] ** $p < 0.01$.

The Table 2 shows that between interactions, the three-way interaction geographical origin * processing system*harvesting time and its associated error accounted for the highest partial η^2 (24%). As per individual factors, highest partial η^2 (30% of the between subject's variance) was attributed to the geographical origin and its associated error. It is worth noting that the three studied factors and their interactions showed sufficient power to detect such effects (the power statistics > 0.80). Several previous studies showed significant effects of geographical origin, processing system and harvesting time on the olive oil quality parameters [10,36]. However, Di Giovacchino et al. [37] showed no significant differences between processing systems in free acidity, peroxide value, K232, K270.

To go further in the analysis of the effect of the geographical origin, processing system and harvesting time on each of the quality parameters, the tests of Between-Subjects effects were used (Table 3). Results showed that the observed statistical power is higher than 0.8 for all significant effects. Accordingly, the tests of Between-Subjects effects have sufficient power to detect such effects.

The interaction geographical origin * processing system was the main contributor to total variance of the free acidity accounting for 21.37%. Moreover, the interaction geographical origin * harvesting time to total variance of peroxide value (18.75%) and K232 (10.69%). In addition, the interaction geographical origin * processing system*harvesting time to total variance of K270 accounting for 22.28% (Table 3).

Table 3. Relative importance of geographical origin, processing system and harvesting time expressed as percentages of total sum of squares and significance in the ANOVA for quality parameters, fatty acid composition, total phenols (TP) and OSI. Means are in % for free acidity (FA), milliequivalent O_2/kg of oil for peroxide value (PV), % for C16:0; C18:0; C18:1; C18:2 and C18:3, mg gallic acid equivalent (GAE)/kg of oil for total phenols (TP), and hours for oxidative stability index (OSI).

Factors/Statistics	FA	PV	K232	K270	C16:0	C18:0	C18:1	C18:2	C18:3	TP	OSI
Geographical origin (A)	11.32 * [1]	18.37 *	8.21	10.36 *	25.10 * [2]	21.03 *	25.67 *	9.11 *	2.26	13.19 *** [3]	13.07 ***
Processing system (B)	10.14 *	0.37	2.46	12.44 *	0.57	0.97	0.99	1.33	1.41	15.92 ***	16.88 ***
Harvesting time (C)	0.57	4.62 *	6.14	4.15	22.59 *	2.97	4.04	6.15	2.68	0.15	5.86 ** [4]
A * B	21.37 *	9.75 *	3.50	6.22	9.76 *	10.13 *	19.94 *	18.09 *	11.28 *	7.82 **	12.61 ***
A * C	2.45	18.75 *	10.69	2.59	1.02	4.40	2.62	8.06	9.59	10.23 **	1.95
B * C	5.39	5.35	4.10	7.25	8.49 *	6.04	8.50	7.75	9.17	8.36 * [5]	5.25
A * B * C	7.27	13.04 *	6.72	22.28 *	1.62	11.59	2.75	1.54	16.50 *	10.77 **	10.84 **
Error	41.50	29.75	58.18	34.72	30.86	42.86	35.49	47.97	47.11	33.55	33.53
Mean	0.94	12.99	1.60	0.14	12.56	3.55	70.47	10.88	0.60	213.09	8.13
CV [6]	69.85	34.75	21.15	31.48	8.68	17.18	2.27	11.21	13.33	29.70	39.82
S.E. Mean [7]	0.06	0.43	0.03	0.00	0.10	0.06	0.15	0.12	0.01	6.12	0.31

[1] * $p < 0.0125$ (Considering the Bonferroni correction for free acidity, peroxide value, K232 and K270; [2] * $p < 0.01$ (Considering the Bonferroni correction for C16:0; C18:0; C18:1; C18:2 and C18:3); [3] *** $p < 0.001$; [4] ** $p < 0.01$; [5] * $p < 0.05$; [6] Coefficient of variation; [7] Standard Error Mean.

As shown in Table 3, the free acidity was significantly affected by the interaction geographical origin*processing system. This revealed that whatever is the geographical origin, the processing system has a significant effect on the free acidity. In addition, the peroxide value was significantly affected by the three-way interaction geographical origin * processing system * harvesting time. This means that the interaction among the two factors (geographical origin * processing system) is different across the levels of the third factor (harvesting time).

Similarly, K270 was significantly affected by the three-way interaction geographical origin * processing system * harvesting time. The interaction among the two factors (geographical origin * processing system) is different across the three harvesting times.

The effect of each factor on the quality parameters of the olive oil was assessed. The effect of the geographical origin was significant on free acidity, peroxide value and K270 (Table 4). These results are in disagreement with those obtained by Lazzez et al. [38] that stated that the fruit ripening is the main factor influencing the olive oil qualitative parameters; and, the geographical origin has only a minor effect on these parameters.

Table 4. Effect of geographical origin on all studied parameters.

Parameters	Akkar	Hasbaya	Jezzine	Zgharta-Koura
FA [1] (%)	1.24 [a 2]	0.43 [c]	1.15 [a]	0.76 [b]
PV [3] (Meq O_2/kg)	14.17 [a]	13.70 [a]	13.71 [a]	8.49 [b]
K232	1.61 [a]	1.74 [a]	1.42 [b]	1.62 [a]
K270	0.15 [a]	0.14 [a]	0.11 [b]	0.15 [a]
C16:0 (%)	13.20 [a]	12.26 [c]	11.83 [d]	12.79 [b]
C18:0 (%)	3.27 [b]	3.41 [b]	3.85 [a]	3.86 [a]
C18:1 (%)	69.74 [b]	71.46 [a]	71.15 [a]	69.42 [b]
C18:2 (%)	11.22 [a]	10.37 [b]	10.63 [b]	11.34 [a]
C18:3 (%)	0.63 [a]	0.60 [a]	0.59 [a]	0.59 [a]
TP [4] (mg GAE/Kg)	208.42 [b]	235.50 [a]	193.53 [b]	217.88 [ab]
OSI [5] (h)	7.97 [b]	10.14[a]	6.42 [c]	8.01 [b]

[1] Free acidity; [2] Different letters (a, b, c) within the same row indicate significant differences ($p < 0.05$); [3] Peroxide value; [4] Total phenols; [5] Oxidative stability index.

Mean comparisons showed that Hasbaya oil recorded the lowest free acidity, Zgharta-Koura oil the lowest peroxide value and Jezzine oil the lowest K232 and K270. However, the oil from Akkar and Jezzine registered the highest free acidity exceeding 0.8% limit established by the IOC regulation for extra virgin olive oil [39], which represented an advanced level of degradation. According to Ben Temime et al. [40], the significant differences in olive oil qualitative parameters between geographical origins are not due to the cultivation area in itself, but to other factors affecting olive fruits quality such as olive fly attacks, mechanical damage during olive harvesting and transport, long delay between harvesting and processing, among others.

When considering only the two phases system that is present only in Akkar and Jezzine, the multivariate analyses of data collected from this system showed a significant effect of the geographical origin on the olive oil quality parameters ($Wilks'\Lambda = 0.53; F = 4.97, p < 0.01$). Yet, the tests of Between-Subjects effects revealed a significant effect of the region only on the K270 parameter ($F(1,25) = 15.81, p < 0.0125$); with higher values in Akkar region (0.18 vs. 0.12). However, if considering only the olive oil samples obtained through the press system, MANOVA shows a very high significant effect of the geographical origin on the olive oil quality ($Wilks'\Lambda = 0.19; F = 5.68, p < 0.001$). The Tests of Between-Subjects effects reveals a significant effect of geographical origin on free acidity and peroxide value with respectively ($F(3,32) = 13.66, p < 0.0125$) and ($F(3,32) = 11.28, p < 0.0125$). The highest acidity was recorded in Jezzine (1.66%) significantly higher than Akkar, Zgharta-Koura and Hasbaya (1.09%, 0.81% and 0.54%, respectively), with Akkar showing significantly higher acidity than Hasbaya. Regarding

peroxide value, Jezzine showed significantly higher peroxide value than Hasbaya and Zgharta-Koura (15.24, 11.58, 7.70 meq O_2/kg of oil). Note that Akkar (14.04 meq O_2/kg of oil) recorded significantly higher peroxide value than Zgharta-Koura (8.49 meq O_2/kg of oil). Also, for the 3-phases processing system alone, MANOVA reveals a very high significant effect of the geographical origin on the olive oil quality ($Wilks'\Lambda = 0.30; F = 3.73, p = 0.0000$). The Tests of Between-Subjects Effects reveals a significant effect of geographical origin on free acidity ($F(3, 32) = 10.95, p < 0.0125^*$); with acidity in Jezzine (0.91%) significantly higher than that in Zgharta-Koura, Akkar and Hasbaya (0.70%, 0.54% and 0.39%, respectively). Note that oils obtained from Zgharta-Koura showed significantly higher acidity than those from Hasbaya. The results of these three comparisons on the same processing systems in different geographical origins confirm that free acidity, peroxide value and K270 are highly dependent on the geographical origins.

As per the processing system, the effect was significant on free acidity and K270 (Table 5). These results are in partial agreement with those obtained by Ben Hassine et al. [36], who indicated that the free acidity, the peroxide value, the K232 and the K270 are significantly affected by the processing system. Conversely, Salvador et al. [41] demonstrated that while oxidative stability and antioxidant content differed significantly between processing systems; free acidity, peroxide value, K232 and K270 didn't show significant differences.

Table 5. Influence of processing system on studied parameters.

Parameters	Press	2-Phases	3-Phases	Sinolea
FA [1] (%)	1.00 [b 2]	1.44 [a]	0.64 [c]	0.36 [c]
PV[3] (Meq O_2/kg)	12.14 [a]	14.30 [a]	12.75 [ab]	13.46 [ab]
K232	1.58 [b]	1.57 [b]	1.57 [b]	1.88 [a]
K270	0.12 [b]	0.16 [a]	0.13 [b]	0.16 [a]
C16:0 (%)	12.49 [ab]	12.84 [a]	12.47 [ab]	12.34 [b]
C18:0 (%)	3.61 [a]	3.54 [a]	3.51 [a]	3.47 [a]
C18:1 (%)	70.35 [b]	70.14 [b]	70.65 [ab]	71.19 [a]
C18:2 (%)	11.01 [a]	10.90 [a]	10.84 [a]	10.47 [a]
C18:3 (%)	0.59 [a]	0.61 [a]	0.61 [a]	0.61 [a]
TP [4] (mg GAE/Kg)	195.86 [b]	240.91 [a]	207.02 [b]	225.89 [ab]
OSI [5] (h)	6.76 [b]	7.07 [b]	9.87 [a]	9.84 [a]

[1] Free acidity; [2] Different letters (a, b, c) within the same row indicate significant differences ($p < 0.05$); [3] Peroxide value; [4] Total phenols; [5] Oxidative stability index.

In the present study, Sinolea system recorded the lowest free acidity; and the 2-phases system, the highest one exceeding, together with the press system, the limit of 0.8% established by the IOC regulation for extra virgin olive oil [39]. These results are in disagreement with many previous studies that showed a highest free acidity in the press system and a lowest one in the centrifugation systems [36,42,43]. The high level of free acidity observed in the present study in the 2-phases system is probably related to strong infection with the olive fruit fly (*Bactrocera olea*) in both regions where the 2-phases is present: Chadra in Akkar and Bisri in Jezzine. The two regions consist of valleys with very high relative humidity and annual high infection with olive fruit fly. Indeed, several previous studies specified that the attack of the olive fly affects negatively the olive oil quality, leading to an increase in free acidity [44,45]. Previous studies stated that, when poor quality olives are industrially processed with either press or 3-phases centrifugation systems the centrifugation system, the latter gave oils with lower free acidity [46]. In the present study, the 2-phases system was unable to reduce sufficiently the free acidity maybe due to the very high infection with the olive fruit fly [44].

Press system and 3-phases decanter recorded the lowest K270 that depends on the presence of secondary oxidation products (conjugated trienes). The higher values observed in 2-phases system also may be due to the high attack of olive fruit fly indicated above; and the higher values in sinolea may be due to the observed high temperature that was used in those mills during the oil processing. These results are in agreement with those described by Gómez-Caravaca et al. [44] who reported an

increase in oxidation products in olive infested by the olive fruit fly; and with those stated by Ranalli et al. [47] who also reported an increase in these products with higher malaxation temperatures.

The results (Table 6) showed that the effect of harvesting time was only significant on peroxide value. It was noticeable that the peroxide value increased significantly in the late harvesting time to 14.91 Meq O_2/kg as compared to the early and intermediate with values of 12.57 and 11.51 Meq O_2/kg, respectively. However, other studies reported an increase only in free acidity along ripening [48,49] due to the progressive activation of the lipolytic activity and to the fact that the olives are more sensitive to pathogenic infections and mechanical damage, which results in oils with higher acidity values [50]. Conversely to the results obtained in the present study, a decrease in peroxide value, K232 and K270 was observed in 'Sayali' olive oils [49] and in other monovarietal olive oils from Tunisia at late harvesting [51]. Bengana et al. [52] reported higher values of all quality indices at late harvest of olive oils from 'Chemlal' variety cultivated in Algeria.

Table 6. Evolution of studied parameters along harvesting.

Parameters	Early Harvest	Intermediate Harvest	Late Harvest
FA [1] (%)	0.89 [a 2]	0.88 [a]	1.04 [a]
PV [3] (Meq O_2/kg)	12.57 [b]	11.51 [b]	14.91 [a]
K232	1.63 [ab]	1.50 [b]	1.66 [a]
K270	0.14 [a]	0.13 [a]	0.14 [a]
C16:0 (%)	12.98 [a]	12.83 [a]	11.86 [b]
C18:0 (%)	3.43 [b]	3.54 [ab]	3.67 [a]
C18:1 (%)	70.52 [ab]	70.10 [b]	70.78 [a]
C18:2 (%)	10.50 [b]	10.94 [a b]	11.20 [a]
C18:3 (%)	0.61 [a]	0.62 [a]	0.58 [b]
TP [4] (mg GAE/Kg)	220.02 [a]	209.85 [a]	209.58 [a]
OSI [5] (h)	9.19 [a]	7.90 [b]	7.31 [b]

[1] Free acidity; [2] Different letters (a, b) within the same row indicate significant differences ($p < 0.05$); [3] Peroxide value; [4] Total phenols; [5] Oxidative stability index.

3.3. Fatty Acid Composition

MANOVA results performed on the set of the five main fatty acids of the olive oil (C16:0, C18:0, C18:1, C18:2 and C18:3) revealed a significant effect of the three-way interaction geographical origin * processing system * harvesting time on the fatty acid composition of olive oil ($p < 0.05$). On the other hand, only the geographical origin and the harvesting time revealed a very highly significant effect on the set of the main fatty acids in olive oil ($p < 0.001$) (Table 2).

The harvesting time and its associated errors accounted for high percentages of the between subject's variance expressed as partial η^2 (37%). In a previous four years study to determine the optimal harvesting period for 'Chemlali' olives, Lazzez et al. [38] also reported that the harvesting time is the factor showing the highest effect on the composition of olive oil in comparison with crop year and growing area.

However, the Tests of Between-Subjects effects revealed that the geographical origin was the main contributor to total variance of C16:0, C18:0 and C18:1. However, the interaction geographical origin * processing system * harvesting time was the main contributor to total variance of C18:3; and, the interaction geographical origin * processing system the main contributor to total variance of C18:2 (Table 3). These results are in agreement with those obtained by Bajoub et al. [53] on the 'Picholine Maroccaine' monovarietal olive oil in Morroco, who reported a significant effect of geographical origin on all fatty acids except on the minor fatty acids, heptadecenoic and myristic acids. Also, there are several studies on the use of fatty acid composition for geographical characterization of olive oils from northern countries of the Mediterranean basin [41,54,55]. On the other hand, the interaction geographical origin * processing system affected significantly all the main fatty acids in the olive oil

(Table 3). This means that whatever is the geographical origin, the main fatty acids of the olive oil are affected by the processing system.

Moreover, the interaction processing system * harvesting time affected significantly the C16:0 (Table 3). This reveals that independently of the processing system, C16:0 is affected by the harvesting time.

Regarding the interaction geographical origin * processing system * harvesting time, it was only significant for C18:3 (Table 3). The mentioned three-way interaction shows that the interaction among the two factors (geographical origin*processing system) is different across the three harvesting times.

As for the effect of each single factor, the mean comparisons showed that C16:0 and C18:2 contents were significantly higher in North Lebanon (Akkar and Zgharta-Koura) than in South Lebanon (Hasbaya and Jezzine). However, C18:1 was significantly higher in South Lebanon (Hasbaya and Jezzine) than in North Lebanon (Akkar and Zgharta-Koura). C18:0 was significantly higher in Jezzine and Zgharta-Koura than in Akkar and Hasbaya. However, the content of C18:3 was not affected by the geographical origin (Table 4). According to Beltrán et al. [56] the air temperature during oil biosynthesis could affect the amount of polyunsaturated fatty acids (linoleic and linolenic fatty acids) by means of the regulation of desaturase enzymes activities. For instance, Issaoui et al. [57] in Tunisia and Mailer et al. [8] in Australia both showed a higher content of C18:1 in cooler regions (high altitudes) and higher contents of C16:0 and C18:2 in warmer regions (low altitudes). The results obtained in the present study agree with these observations as the high C18:1 content was observed in the olive samples proceeding from Jezzine and Hasbaya where the olive fruits were harvested at altitudes up to 1000 and 1050 m, respectively; and, the high content of C16:0 and C18:2 were observed in oils from Zgharta-Koura and Akkar as the fruits were harvested from lower altitudes, up to 350 and 700 m respectively. Although, Serhan et al. [24] also previously reported strong negative correlation between altitude and C16:0, additional studies on several years and involving different regions in North and South Lebanon are essential to prove these hypotheses.

It is worth noting that, the effect of processing system on the fatty acid composition was not significant in the present study (Table 5), in concordance with the results obtained by Gimeno et al. [42] and by Serhan et al. [24] while comparing traditional and centrifugation processing systems in north Lebanon; but, in partial agreement with those obtained by Salvador et al. [41] who reported slight differences in fatty acid composition due to the processing system, although the differences were significant only in case of C16:0, C16:1 and C18:3.

However, regarding the harvesting time, the effect was only significant on C16:0 whose content decreased significantly after the intermediate harvesting time (Table 6). These results are in agreement with those reported by Cimato [5] where the delay in harvesting tended to increase the content of unsaturated fatty acids, especially linoleic, at the expense of palmitic acid. However, these results are partially in agreement with those obtained by Baccouri et al. [51] on Tunisian monovarietal olive oil and by Fuentes de Mendoza et al. [48] in a three successive years study on 'Morisca' and 'Carrasqueña' olive varieties, who reported a decrease in palmitic and linoleic acids along ripening.

3.4. Total Phenols

The effect of the studied factors and their interactions on total phenols content, determined by the Folin-Ciocalteu method, was assessed. Results showed that the interaction geographical origin * processing system * harvesting time showed a highly significant effect on total phenols ($p < 0.01$) (Table 3). This three-way interaction geographical origin * processing system * harvesting time means that whatever is the geographical origin, the processing system has a significant effect on the total phenols content for the three harvesting times. Indeed, the interaction among the two factors (geographical origin * processing system) is different across the early, intermediate and late harvest.

As per each factor alone, very highly significant effects of geographical origin and processing system were observed on the total phenols content $(p = 0.0000)$, with the later showing the highest contribution (15.92%) and the former the second one (13.19%) (Table 3). Mean comparisons showed

that total phenols in Hasbaya was significantly higher than in Akkar and Jezzine (235.50, 208.42 and 193.53 mg GAE/Kg of oil, respectively); while, the total phenols in Zgharta-Koura recorded an intermediate value (217.88 mg GAE/Kg of oil) (Table 4). These results don't match those shown by Baccouri et al. [51] that reported no difference in phenolic compounds according to the geographical origin in monovarietal olive oils from Tunisia; but they match those shown by Ben Temime et al. [40] and Youssef et al. [58] that reported different phenolic composition in 'Chétoui' and 'Oueslati', respectively, due to different climate and soil characteristics. Moreover, regarding the processing system, the oil from 2-phases system recorded significantly higher total phenols than 3-phases and press systems (240.91, 207.02 and 195.86 mg GAE/Kg of oil, respectively); however, sinolea system recorded an intermediate value (225.89 mg GAE/Kg of oil) (Table 5). Salvador et al. [41] previously reported that among all quality and compositional parameters of olive oil, phenolic compounds and oxidative stability stand as the main parameters affected by the processing system. In fact, it was demonstrated that the 2-phases decanter preserves more of the phenolic compounds in comparison to the 3-phases decanter where the added water causes large amounts of phenols to be eliminated with the olive mill waste water [42] (12, 16). Moreover, the high amount of O_2 dissolved in the pastes during the process of press and sinolea systems due to contact with the air result in a loss of phenolic compounds due to the activation of endogenous enzymes, polyphenoloxidase and peroxidase, that oxidize the phenolic compounds and consequently reduce their concentration in the produced oil [14].

However, regarding the harvesting time, the total phenols content decreased along ripening although the difference was not significant. This decrease in total phenols with the progress of ripening was previously well reported [35,49].

3.5. Oil Oxidative Stability (OSI)

To understand the effect of the three studied factors on the OSI, a three-way ANOVA was run. Results showed a highly significant effect ($p < 0.01$) of the three-way interaction geographical origin * processing system * harvesting time (Table 3); which means that regardless of the geographical origin, the processing system has a significant effect on the OSI for the three-harvesting time. Indeed, the interaction among the two factors (geographical origin*processing system) is different across the early, intermediate and late harvest.

As per each factor alone, the OSI was extremely highly significantly affected by the geographic origin and by the processing system ($p < 0.001$); and, highly significantly affected by the harvesting time ($p < 0.01$). It is worth to note that Hasbaya oil showed significantly higher OSI (10.14 h) followed by Zgharta-Koura, Akkar and Jezzine 8.01, 7.97, and 6.42 h, respectively) (Table 4). Interestingly, this was the same tendency observed in total phenols, in agreement with previous results showing a high positive correlation (r = 0.937) between total phenols in oils from different locations and OSI [59].

However, the 3-phases and the sinolea systems registered significantly higher OSI (9.87 and 9.84 h, respectively) in comparison with 2-phases and press systems (7.07 and 6.76 h, respectively) (Table 5). Although the 2-phases registered the highest phenolic content, the lower OSI recorded in this system could be mainly due to the higher free acidity registered in oils from this system. In previous studies, Rotondi et al. [60] have found a high positive correlation between higher free acidity and shorter shelf life of olive oil.

As per the harvesting time, the OSI decreased along ripening in parallel to the decrease of total phenols. The difference was only significant between the first and the last harvesting time (Table 6).

3.6. Sensory Characteristics

The consumer preferences and experienced sensorial panel judgment were conducted only on olive oil samples qualified chemically as extra virgin olive oil.

3.6.1. Consumer Preferences

In order to show the difference in consumer preferences among the 50 olive oil samples studied, the Friedman test was run. This test showed very highly significant differences ($\chi^2(6) = 154.85$, $p < 0.001$), indicating that the observed difference in the participant's choice is due to the olive oil itself and not to any other random factor. Moreover, the "Kendall's W" recorded a value of 0.53, indicating a mid-difference among the participant's choices (a Kendall's W value equal 1 indicates a complete agreement between consumers, and a Kendall's W value equal 0 indicated a complete disagreement).

The results of Friedman test (Table 7) show that the mostly preferred olive oil samples were two among three samples of Hasbaya sinolea olive oils obtained from the first harvesting time and one Jezzine press olive oil from the third harvesting time with mean ranks of 40.83. However, the secondly preferred ones were two among three of Hasbaya sinolea olive oils and Hasbaya 3-phases olive oils and 1 among three of the Hasbaya press olive oils all at the second harvesting time with mean ranks 36.7. The statement that different replicates of oils originating from the same geographical origin, processing system and harvesting time were differently judged could be due most likely to the fact that the tasters (consumers) were different or to the fact that the different replicates belong to different olive lots. It is greatly reported that the sensory characteristics of olive oil are correlated with the sample chemical composition, especially to the phenolic and fatty acid content and profile. Moreover, it is reported that the oil produced by the 2-phases has intense bitter and pungent tastes resulting from the higher phenolic content, which may be unpleasant for some consumers that are not familiar with this oil taste [16]. Therefore, it is suggested to conduct further correlation to identify the relationship between the consumer preferences and the specific chemical composition. Moreover, the quality of olive oil is not always correctly perceived by the consumer, especially since they generally appreciate what is familiar and what is strongly linked to their tradition and origin [61,62].

It was noticeable that 50% of the samples (25 samples) recorded the lowest rank. Note that the judgment of the consumers was not unanimous with regard to geographical origin, processing system and harvesting time.

Table 7. Consumer preferences and the experienced sensorial panel judgments of the samples studied.

Sample ID	Consumers Preferences				Panel Judgment			
	N	Like (%)	Don't Like (%)	Mean Rank	Classification	Fruity	Bitter	Pungent
A Press HT1R2	20	15.0	85.0	20.0	Defected	-	-	-
A Press HT3R3	31	25.8	74.2	20.0	Defected	-	-	-
A 2-Phases HT1R1	15	60.0	40.0	20.0	Missing	-	-	-
A 2-Phases HT1R2	14	7.1	92.9	20.0	EVOO	Delicate	Delicate	Medium
A 2-Phases HT1R3	16	56.3	43.8	20.0	Defected	-	-	-
A 3-Phases HT1R1	23	26.1	73.9	20.0	EVOO	Delicate	Delicate	Delicate
A 3-Phases HT1R3	24	62.5	37.5	20.0	EVOO	Delicate	Delicate	Delicate
A 3-Phases HT2R1	10	60.0	40.0	28.3	EVOO	Delicate	Delicate	Delicate
A 3-Phases HT2R2	13	61.5	38.5	24.2	EVOO	Delicate	Delicate	Delicate
A 3-Phases HT2R3	28	57.1	42.9	20.0	EVOO	Delicate	Delicate	Delicate
A 3-Phases HT3R1	14	78.6	21.4	32.5	EVOO	Delicate	Delicate	Delicate
A 3-Phases HT3R2	22	31.8	68.2	20.0	EVOO	Delicate	Delicate	Delicate
A 3-Phases HT3R3	22	63.6	36.4	20.0	EVOO	Delicate	Delicate	Delicate
H Press HT1R1	6	33.3	66.7	28.3	Defected	-	-	-
H Press HT1R2	11	45.5	54.5	20.0	Defected	-	-	-
H Press HT1R3	16	25.0	75.0	20.0	EVOO	Medium	Delicate	Medium
H Press HT2R1	11	36.4	63.6	20.0	EVOO	Delicate	Delicate	Delicate
H Press HT2R2	11	27.3	72.7	20.0	EVOO	Medium	Delicate	Medium
H Press HT2R3	9	77.8	22.2	36.7	EVOO	Medium	Delicate	Delicate
H Press HT3R2	16	18.8	81.3	20.0	Defected	-	-	-
H Press HT3R3	11	36.4	63.6	20.0	Defected	-	-	-
H 3-Phases HT1R1	7	57.1	42.9	32.5	EVOO	Medium	Delicate	Medium
H 3-Phases HT1R2	9	44.4	55.6	24.2	EVOO	Medium	Delicate	Delicate
H 3-Phases HT1R3	7	42.9	57.1	28.3	EVOO	Delicate	Delicate	Delicate
H 3-Phases HT2R1	17	64.7	35.3	20.0	EVOO	Medium	Delicate	Medium
H 3-Phases HT2R2	7	71.4	28.6	36.7	EVOO	Delicate	Delicate	Delicate
H 3-Phases HT2R3	7	71.4	28.6	36.7	EVOO	Delicate	Delicate	Medium
H Sinolea HT1R1	11	90.9	9.1	40.8	EVOO	Delicate	Delicate	Delicate
H Sinolea HT1R2	11	90.9	9.1	40.8	EVOO	Delicate	Delicate	Delicate
H Sinolea HT1R3	16	31.2	68.8	20.0	EVOO	Delicate	Delicate	Delicate
H Sinolea HT2R1	6	66.7	33.3	36.7	EVOO	Delicate	Delicate	Delicate

Table 7. *Cont.*

Sample ID	Consumers Preferences				Panel Judgment			
	N	**Like (%)**	**Don't Like (%)**	**Mean Rank**	**Classification**	**Fruity**	**Bitter**	**Pungent**
H Sinolea HT2R2	9	77.8	22.2	36.7	EVOO	Delicate	Delicate	Delicate
H Sinolea HT2R3	11	45.5	54.5	20.0	EVOO	Medium	Delicate	Medium
H Sinolea HT3R2	11	54.5	45.5	24.2	EVOO	Delicate	Delicate	Delicate
H Sinolea HT3R3	16	56.3	43.7	20.0	EVOO	Medium	Delicate	Delicate
ZK Press HT1R3	10	50.0	50.0	24.2	Defected	-	-	-
ZK Press HT2R1	8	50.0	50.0	28.3	Defected	-	-	-
ZK Press HT3R1	13	69.2	30.8	28.3	Defected	-	-	-
ZK Press HT3R2	8	37.5	62.5	24.2	Defected	-	-	-
ZK 3-Phases HT1R1	7	14.3	85.7	20.0	EVOO	Delicate	Delicate	Delicate
ZK 3-Phases HT1R2	13	53.8	46.2	20.0	EVOO	Delicate	Delicate	Delicate
ZK 3-Phases HT1R3	10	40.0	60.0	20.0	Defected	-	-	-
ZK 3-Phases HT2R3	10	70.0	30.0	32.5	Defected	-	-	-
ZK 3-Phases HT3R2	13	69.2	30.8	28.3	Defected	-	-	-
J Press HT3R3	7	85.7	14.3	40.8	Defected	-	-	-
J 2-Phases HT1R1	10	50.0	50.0	24.2	Defected	-	-	-
J 2-Phases HT3R1	8	62.5	37.5	32.5	Defected	-	-	-
J 3-Phases HT1R2	13	30.8	69.2	20.0	Defected	-	-	-
J 3-Phases HT1R3	10	50.0	50.0	24.2	Defected	-	-	-
J 3-Phases HT2R1	7	14.3	85.7	20.0	Defected	-	-	-

A: Akkar; H: Hasbaya; ZK: Zgharta-Koura; J: Jezzine; HT1, HT2 and HT3 represent early, intermediate and late harvest time respectively; R1, R2 and R3 represent the three repetitions (3 different olive lots)

3.6.2. Experienced Sensorial Panel

The panel judgment on olive oils without defects showed that all tasted oils fall within the delicate and medium categories. This could be due to the fact the oil samples were stored for a long period at −20 °C before the tasting sessions. It is worth highlighting that the samples with the highest mean rank by consumers were all appreciated by the expert panelists except for the sample obtained from Jezzine using the press system in the late harvest.

It is worth to noting that the Chi square test showed a significant relation between the consumer preferences and the olive oil panel judge as defected or without defects ($\chi^2(1) = 4.87; p < 0.05$). These results show that the consumers, even naïf, were able to discriminate 70.0% of the defected samples and 62.1% of the samples without defects. Similarly, Predieri et al. [63] reported that the results from consumers and trained panelist are comparative.

The effect of geographical origin, processing system and harvesting time on the positive attributes of olive oil was also performed. The results showed no significant effect ($p > 0.05$). Similarly, Di Giovacchino et al. [37] showed no significant differences between processing systems and sensorial properties of olive oil. Although several studies reported that geographical origin, processing system and harvesting time were major factors significantly affecting the olive oil sensory characteristics, none of the studies have assessed the combined effect of a big sample size.

4. Conclusions

This study reported, for the first time, the results of the complex interaction between the geographical origin, harvesting time and processing system on the olive oil chemical and sensorial characteristics. The overall findings showed that the fatty acids composition including C16:0, C18:1 and C18:2 was mainly affected by the geographical origin. This highlights the need to conduct further studies in order to identify protected denominations of origin in Lebanon. Findings also showed a significant effect of harvesting time on the peroxide value and OSI; and, of the processing system on the free acidity, total phenols and the OSI. Moreover, this study has showed that consumer preference was not influenced by the geographical origin, harvesting time and processing system but could be affected by olive oil chemical composition. The findings of this study, therefore, may help experts and producers to draw more attention to the most adequate processing parameters and their combinations in order to produce the highest olive oil chemical and quality characteristics that suit specific customer preferences.

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