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Susceptibility of eight Algerian olive cultivars to *Bactrocera oleae* infestation – a pomological and nutritional quality perspective

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Abstract The olive fruit fly, *Bactrocera oleae* (Rossi), is the major olive pest in the Mediterranean Basin, being responsible for high losses in olive production. The objective of this work was to study the influence of *B. oleae* infestation on the pomological parameters and nutritive value (lipids, proteins, carbohydrates and ash) of eight olive cultivars (*Abani, Aellah, Blanquette de Guelma, Chemlal, Ferkani, Limli, Rougette de Mitidja* and *Souidi*) from Algeria. The results displayed different degrees of susceptibility of the studied cultivars to this pest. Fruit size (weight) and the Fruit weight / stone weight ratio are significantly correlated with the attack. The statistical treatment of the results (PCA and HAC) highlighted different behaviors from the cultivars, concerning the attack. There are some cultivars more susceptible, being the nutritional value also affected. The lipid and protein contents were positively correlated with the attack and the carbohydrates negatively, suggesting a careful choice by the *B. oleae.* Ovipositional preference of olive fruit fly females and the success of larval development in different olive cultivars are crucial to establishing new approaches in *Integrated Pest Management* (IPM) against this pest.

Keywords Olive fly · Nutritional composition · Olive · Pomological characteristics

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Introduction

All over the world, olive trees represent 11 million ha, producing 2.7 million tons of table olives and 2.9 million tons of olive oil. From that, 96% is produced by the Mediterranean region where olive trees play a major socio-economic role (IOOC 2016). According to the literature, olive tree was domesticated in the eastern Mediterranean about 10.000 years ago. Olive tree has a great diversity of cultivars, being currently known more than 1200 worldwide (Genç 2016). In Algeria, olive growing is one of the most important tree crops. This sector has grown significantly over the past four years, from 200.000 ha in 2011 to 401.181 ha in 2015. A wide range of cultivars characterizes the Algerian olive grove, and a collection with 36 cultivars exists at the ITAFV (Technical Institute for Fruit Trees and Vine) of Bejaia (East center of northern Algeria).

The olive fruit fly, *Bactrocera oleae (*Rossi) (Diptera: Tephritidae), is one of the most important olive pests in the world (Daane and Johnson 2010), especially in the Mediterranean basin (Tzanakakis 2006). This monophagous pest can attack olive fruits from cultivated or wild trees. Their larvae have the unique capability of feeding on olive mesocarp, dealing with high levels of phenolic

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compounds and using non-hydrolyzed proteins present, particularly, in the unripe green olives (Ben-Yosef et al. 2015; Pavlidi et al. 2017). This ability is associated with the presence of symbiotic bacteria of which *Candidatus* Erwinia dacicola was the predominant species (Capuzzo et al. 2005; Sacchetti et al. 2008).. The direct damage of pests could reduce at least 15% of the worldwide production of olives (Bueno and Jones 2002). The economy impact of this pest on olive sector could be huge, mostly due to the oviposition activity of the adult fly and larval feeding (Gümusay et al. 1990), leading to the fruit fall and a decrease in oil content and its quality (Tamendjari et al. 2004, 2009, 2011; Gómez-Caravaca et al. 2008; Medjkouh et al. 2016, 2018).

Nevertheless, the olive fruit fly does not affect all olive cultivars in a same way since their susceptibility is different (Scarpati et al. 1996; Daane and Johnson 2010). Some olive cultivars consistently show lower levels of infestation when compared to others in the same geographical conditions (Daane and Johnson 2010).Thus, the interaction between olive fly and olive tree characteristics can be useful to identify and explain the different susceptibility of some cultivars to oviposition and must be evaluated. Until now, the main aspects studied were physical parameters (Tzanakakis 2006; Rizzo et al. 2012), chemical (Daane and Johnson 2010; Malheiro et al. 2015a; Garantonakis et al. 2016) and molecular composition (Corrado et al. 2012; Grasso et al. 2017). More recently, it has been shown that fungi and bacteria were also implied in the complex relationship between fly and olive fruit (Liscia et al. 2013).

In this way, the characterization of cultivars and the evaluation of their susceptibility to the olive fruit fly are of huge importance to improve the quality of the olive oil produced in Algeria. The aim of this work is to study the susceptibility of eight Algerian cultivars of olive trees to olive fruit fly, focusing in the pomological parameters (weight, length and width of fruits and stones) and the impact of the fly attack on the nutritional value (lipids, carbohydrate, protein and ash contents and energy) of olives.

Material and methods

Sampling

Olives from eight Algerian olive cultivars, *Abani* (A), *Aellah* (E), *Blanquette de Guelma* (B), *Chemlal* (C), *Ferkani* (F), *Limli* (L), *Rougette de Mitidja* (R) and *Souidi* (S) were harvested during the season of 2014–15. The olives were hand-picked at Takerietz (Sidi-Aich, southern Bejaia) in the ITAFV (Technical Institute for Fruit Trees and Vine) located at 36 °, 36 ', 47" North and 4 °, 41 ', 18″ East at an altitude of 111 m. The eight cultivars studied are used for oil production. *Chemlal,* the main cultivar, occupies 40% of the Algerian olive orchards and *Limli* occupies 8% of the total olive area. *Ferkani,* a local cultivar with a very high oil yield (between 28 and 32%), is currently expanding in the steppe and Saharan regions. The other cultivars are autochthonous cultivars. Concerning their maturity cycle, *Abani, Aellah, Souidi, Ferkani* and *Limli* are early maturing varieties. *Chemlal* and *Blanquette de Guelma* are late varieties. *Rougette de Mitidja*is a seasonal cultivar.

Approximately 3 kg of olive fruits were collected from each tree (in a total of four samples per cultivar) at head height and along the four cardinal points of each tree and immediately transferred to the laboratory.

Determination of infestation and maturity index

The percentage of attack was determined by the number of olives infested (presence of larvae, pupae or exit holes) in a batch of 100 olives, taken randomly after harvesting.

The maturity index (MI) was determined according to the IOOC method (IOOC 2011).The formula used is based on a pointing system corresponding to each stage of coloration of the pericarp and the mesocarp.

Morphological aspect of olives

Olive and stone weights were determined in 100 drupes taken randomly from a homogenized sample (Jiménez et al. 2013).The length and width of the olives and stones were measured by means of a caliper.

Samples preparation

After determination of the MI and attack level (larvae + pupae + number of exit holes), the olives were grouped into 3 lots: S - constituted only by healthy olives (not attacked by *B. oleae*); N - natural olives (reflecting the real attack rate); A -only attacked olives (each olive has at least one exit hole). Each lot was evaluated separately to verify differences among groups.

Samples lyophilisation (1 Kg of olives) was performed according to the following steps: olive cutting into thin pieces and frozen at −80 °C; lyophilisation at −58 °C; finally, grinding in an electric mixer and stored until analysis.

Nutritional analysis

The protein content (N × 6.25) was determined using the Kjeldahl method (AOAC 2012). Briefly, 0.2 g of sample weighted in a nitrogen-free paper was placed in a Kjeldahl digestion tube with two catalytic Kjeldahl tablets, and 20 mL of concentrate sulphuric acid. The samples were digested at 500 °C, in a Speed Digester K-424 from BUCHI for 1 h and then distilled and titrated. The results were presented as % of dry matter.

Total fat was determined by Soxhlet (AOAC 2012), using an extraction system from BUCHI. Briefly, 5 g of olive sample was placed in an extraction thimble of cellulose with anhydrous sodium sulphate and petroleum ether at 40–60°, used as extraction solvent. After removing the solvent, the lipids were weighted. The results were expressed as % of dry matter.

The ash content was determined by incineration of the sample in a muffle furnace (Thermolyne 48,000 Furnace) at 500 °C (AOAC 2012). Results were expressed as percentage of dry matter.

The total carbohydrates content was determined by difference.

The energy was calculated using the conversion factors for each nutrient (Pimentel et al. 2014).

$$\text{Energy (kcal)} = 4 \times (\text{g protein}) + 3.75 \times (\text{g carbohydrates}) + 9 \times (\text{g lipids})$$

Statistical analysis

Statistical analysis was carried out using the software Statistica 5.5. For each parameter, the analysis of variance ANOVA is used followed by the Newman & Keuls test with a confidence level of 95% ($p < 0.05$). The principal component analysis (PCA) and hierarchical ascending classification (HAC) are performed by XLSTAT 2009.1.02.3.

Results and discussion

Olive morphological aspect, maturity index and infestation

The maturity index (MI), the percentage of attack, weight and other dimensions of the studied olive samples from eight Algerian cultivars are summarized in Table 1. The results showed significant differences from the morphological point of view among the cultivar characteristics (fruit and stone weight, length and width) as well as MI and attack ($p \leq 0.05$).

In what concerns to pomological dimensions, *Rougette de Mitidja* had the highest weight olives (2.81 g) followed by *Blanquette de Guelma* (2.59 g). Inversely, *Souidi* presented the lowest weight drupes (0.97 g). All the cultivars had significant differences in fruit weight, except *Aellah* and *Limli,* which fruits*,* have similar weights (1.81 and 1.77 g). Stone weight showed significant differences among the eight cultivars, with *Abani* presenting the lowest stone and *Rougette de Mitidja* the heaviest one. Concerning the fruit width, the differences were not evident, with *Souidi* presenting the lowest diameter and *Blanquette de Guelma* the largest one. According to Table 1 stone widths varied between 0.78 (*Souidi*) and 0.93 cm (*Rougette de Mitidja*), with similar values among the cultivars in evaluation.

Regarding the pomological parameter length, once more *Souidi* presented the smaller fruit while *Abani* and *Aellah* showed the longest ones. In the case of stones length, *Souidi* had the smallest and *Rougette de Mitidja* the longest. Thus, the ratio fruit weight/stone weight (FWe/ SWe) is minimal in *Souidi* and *Chemlal* and maximal in *Aellah*, *Blanquette de Guelma, Ferkani* and *Rougette de Mitidja.* All cultivars showed significant differences for MI, being *Souidi* the cultivar with the highest value and *Ferkani* with the lowest one.

The pomological parameters, namely the olive fruits weight, play an important role and a significant influence on their susceptibility to *B. oleae. Rougette de Mitidja*, with its large fruits, showed the highest attack rate (65.33%), while *Souidi* with the smallest drupe presented the lowest (21%), similar to *Chemlal* (21.33%). This appreciation is in agreement with the previous discussion already made for the other pomological parameters. Considering the two parameters, MI and attack, their correlation is not clear, taking into account the values presented for *Ferkani* and *Limli*. These cultivars had similar percentage of attack (without significant

Table 1 Weight, dimensions, maturity index and % of infestation of the eight olive cultivars

Cultivar	Maturity index (MI)	% infestation (%)	Fruit weight (g)	Stone weight (g)	Fruit width (cm)	Stone width (cm)	Fruit length (cm)	Stone lenght (cm)	FW/SW
Abani	5.743 ± 0.012 f	34.67 ± 0.94 b	1.61 ± 0.1 c	0.324 ± 0.002 a	1.417 ± 0.069 bc	0.82 ± 0.04 ab	2.27 ± 0.09 c	1.82 ± 0.09 b	4.98 ± 0.11c
Aellah	5.94 ± 0.008 g	51.33 ± 2.62 cd	1.81 ± 0.01 d	0.33 ± 0.003 b	1.467 ± 0.17 bc	0.82 ± 0.11 ab	2.38 ± 0.16 c	1.77 ± 0.16 b	5.5 ± 0.14d
Blanquette de Guelma	5.55 ± 0.008 e	59 ± 1.63 ef	2.59 ± 0.03 f	0.453 ± 0.001 g	1.583 ± 0.227 c	0.87 ± 0.05 ab	2.,1 ± 0.36 bc	1.75 ± 0.08 b	5.73 ± 0.06 d
Chemlal	4.42 ± 0.008 c	21.33 ± 2.87 a	1.17 ± 0.05 b	0.443 ± 0.002 f	1.2 ± 0.115 ab	0.87 ± 0.05 ab	1.77 ± 0.25 ab	1.47 ± 0.07 a	2.65 ± 0.29 a
Ferkani	3.337 ± 0.097 a	44.67 ± 6.85 bc	2.35 ± 0.05 e	0.418 ± 0.001 e	1.45 ± 0.096 bc	0.87 ± 0.11 ab	2.08 ± 0.15 bc	1.5 ± 0.14 a	5.61 ± 0.08 d
Limli	4.23 ± 0.008 b	41.33 ± 3.09 bc	1.77 ± 0.07 d	0.395 ± 0 d	1.283 ± 0.157 ab	0.83 ± 0.07 ab	1.93 ± 0.37 abc	1.52 ± 0.13 a	4.49 ± 0.11 b
Rougette de Mitidja	4.67 ± 0.008 d	65.33 ± 8.99 f	2.81 ± 0.05 g	0.496 ± 0 h	1.367 ± 0.243 bc	0.93 ± 0.05 b	2.12 ± 0.25 bc	2.05 ± 0.15 c	5.68 ± 0.03 d
Souidi	6.54 ± 0.008 h	21 ± 0.82 a	0.97 ± 0.02 a	0.34 ± 0.002 c	1.083 ± 0.09 a	0.78 ± 0.04 a	1.65 ± 0.14 a	1.55 ± 0.11 a	2.86 ± 0.17 a

Different letters within each column indicate a significant difference between samples ($P < 0.05$). The results are arranged in ascending order; a < b < c < d < e < f < g < h

differences, intermediate values for this parameter) but different MI (the lowest ones, 3.34 and 4.23).Two other cultivars, *Abani* and *Blanquette de Guelma*, have similar maturity index (5.74 and 5.55 respectively), and a widely different percentage of attack (34.67 and 59%, respectively). These different behaviors are justified by the weight of the drupe, being always higher the percentage of attack in the heavy fruits. A significant positive correlation ($r = 0.91$, $p < 0.05$) was found between attack and fruit weight. Other characteristics with significant positive correlations ($p < 0.05$), were fruit width (FWi) ($r = 0.67$) and fruit length (FL) ($r = 0.55$).Taking into account the referred above, it can also be inferred that fruit weight / stone weight ratio (FWe / SWe) inform about the susceptibility of the cultivars to the attack. Thus, the varieties with low values, which means with a small pulp thickness, were the least attacked. *Souidi* and *Chemlal* with ratios of 2.86 and 2.65 respectively, are examples of the referred. They have the lowest ratios and percentage of attack, and a significant positive correlation was noted ($r = 0.86$, $p < 0.05$). These behaviors are similar to those described by Neuenschwander et al. 1985; Wang et al. 2009; Rizzo et al. 2012; which verified the preference of olive fly for large-fruit varieties for spawning. Recently, Garantonakis et al. (2016) evaluated the susceptibility of seven olive cultivars (*Koroneiki, Mastoidis, Picholine, Manzanilla, Arbequina, Branquita and Leccino*), representing the major European Mediterranean olive-producing countries cultivars, harvested in November 2013 in Greece. They found that *B. oleae* infestation was positively correlated with length (0.442, $p < 0.01$), width (0.613, $p < 0.01$) and fresh weight of the fruits (0.619, $p < 0.01$). Total fruit infestation by *B. oleae* was highest for *Manzanilla*, *Leccino* and *Picholine;* the lowest values were recorded in *Arbequina* and *Mastoides.*

Another point of interest is the development of the fruit along the season. Fruit weight generally increases with the progression of the season (Dag et al. 2011). According to Edriss et al. (2008), in a study with *Aldeibli* cultivar, the fly begins laying its eggs only when the average weight of the fruit is greater than 0.8 g, for an average final weight of 1.7 g. Studies in the laboratory indicate that fly prefers fruits with a diameter of 7.5 mm in comparison to small fruits (Al-Salti et al. 2011). These results confirm those already reported by Antonelli and Chesi (1985) in which the attack rate increases with increasing weight, diameter and length of the fruits. Mesbah and Megda (1996) also highlighted the relationship between olive size and percentage of fly attack. Conversely, Gonçalves et al. (2012) reported that the fruit size is not a key factor determining ovipositional preference.

The maturation process is another factor that can affect the cultivars susceptibility, due to its influence on the fruit characteristics and color. Gümusay et al. (1990) and Rizzo et al. (2012) reported that late olive maturation would be conducive to attack due to the persistence of green color. For Afellah et al. (1997), it is mainly during the autumn that the cultivar maturation evolves, justifying the attack levels of Picholine, with the late maturation.

The studied cultivars with low MI (*Ferkani, Chemal and Limli*) are not the most attacked. The obtained results are in agreement with Neuenschwander et al. (1985) but in disagreement with Gümusay et al. (1990) and Malheiro et al. (2015b), which noted that a slower maturation process have an attraction effect to olive fly. It is possible that the fly prefers the fruits with a low hardness of the epicarp to easily penetrate the laid egg. Sharaf (1980) verified that a small fruit size and a high hardness reduce the attack rate. In the same sense, Gümusay et al. (1990) referred that fruits with soft skin are most susceptible to attack.

In order to obtain a better representation of the different samples and to define categories, a Hierarchical Ascending Classification (HAC) and Principal Component Analysis (PCA) were carried out (Fig. 1).

The projection of the samples on the factorial plane F1-F2 of the PCA (Fig. 1) allow to verify the variability among the individuals, by their dispersion on the two axes, explaining 81.24% of the total variance. The axes 1 and 2 explain 55.85 and 25.39%, respectively. It was verified a positive correlation of F1 axis and the variables fruit weight (FWe), fruit width (FWi), and stone width (SWi), with values of 0.961, 0.846 and 0.845, respectively. Stone weight (SWe) is positively correlated with axis 2 while fruit length (FL) is negatively correlated with such axis. The best correlations between variables were FWe -attack with $r = 0.941$; FWe-FWi (0.807); FWi- I% (0.807); FWe -SWi ($r = 0.753$), thus, mainly associated with the size of the fruits.

HCA, also called Clustering Analysis, allows the representation of the samples in groups and subgroups by using a dendrogram from Euclidean distances. The results obtained (Fig. 2) reveal a classification of individuals into four groups:

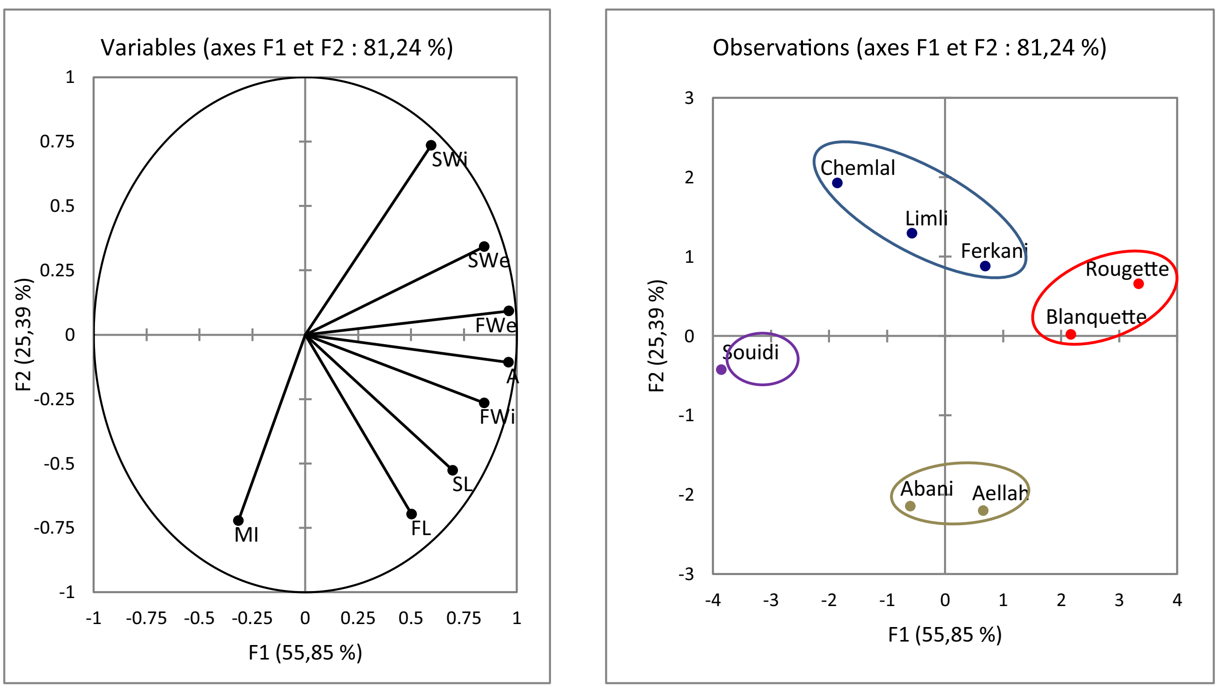

Fig. 1 Factorial plans 1–2 of the ACP according to the pomological parameters, weight and dimensions of the fruits and stones, % of attack and maturity. MI: maturity index; A: attack; FWe: Fruit weight; SWe: Stone weight; FL: Fruit length; FWi: fruit width; SL: Stone length; SWi: Stone width

- Group 1: composed *Souidi* cultivar, characterized by its small fruits, low percentage of attack and a higher MI.
- Group 2: With two subgroups, one represented by individuals of *Ferkani* and the other by individuals of *Chemal* and *Limli* cultivars. The percentage of attack is proportional to the fruit weights and the two varieties have close MI.
- Group 3: represented by Abani and *Aellah* samples, with very close weights and MI.
- Group 4: including the two large fruit varieties, *Blanquette de Guelma* and *Rougette de Mitidja,* which are the most attacked by the olive fly.

Nutritional value

Table 2 summarizes the nutritional value (total lipids, proteins, carbohydrates and ash) and energy determined in fruits of the olive cultivars in evaluation.

Olive fruits with three different attack rates were considered (without attack, S; all attacked, A; and natural rate, N). As the samples for nutritional evaluation were lyophilized, the moisture contents were considered the same for all.

Lipids constitute the major compounds in six cultivars, ranging from 36 to 71%. Only two cultivars have contents lower than 45% (*Chemlal* and *Souidi*). The cultivar with the highest lipids levels was *Ferkani*. The influence of the attack level and the loss of lipids were clearly demonstrated. The losses were more pronounced in 100% attacked samples (A), comparatively to the natural rate (N) and samples without attack (S). Thus, the attack of olives by *B. oleae*, represents an important decrease of olive oil production and consequently of economical incomes. The losses ranged between 15% (*Aellah*) and 42% (*Blanquette de Guelma*). Considering the pomological parameters there are not a clear association between the fruit weight and the lipids loss. *Rougette de Mitidja*, characterized by the heavy fruits, has an intermediate loss value (32%) comparatively to *Souidi*, the cultivar with lighter fruits and a loss of 41%. Nevertheless, a significant positive correlation was noted between lipid content and attack ($r = 0.72$, $p < 0.05$).The high proportion of oil during the first period of fruit ripening can contribute to an improved attraction of the fly (Sharaf 1980; Al-Salti et al. 2011). Oviposition preference was previously positively correlated with the oil content of Portuguese cultivars (Gonçalves et al. 2012).

Concerning carbohydrates content, the cultivars in evaluation showed different amounts. Conversely to the lipids, a significant negative correlation was found between carbohydrates and attack (−0.67, $p < 0.05$). *Chemlal* and *Souidi,* the richest cultivars in carbohydrates (59 and 56%, respectively) are the less attacked with rates of 21%. *Blanquette de Guelma* is not affected by *B. oleae* attack and showed a stable carbohydrate content. The more pronounced losses were verified in *Rougette de Mitidja* samples (33%). However, the other samples were also affected with decreasing contents ranging from 13 (*Aellah*) to 20% (*Chemlal*).

The protein levels are of utmost importance for the larval development. The local microbiological contamination helps flies to break down olive fruit components, such as proteins, into essential amino acids and peptides, required for larval growth in unripe olives (Athar 2005). A biological process seems to be activated during the development of larvae in olives, with the most notable being the activation of amino-acid metabolism (Pavlidi et al. 2017). Olive pulp contains a protein content that ranged between 2.62 (*Souidi*) and 5.25% (*Aellah*). A

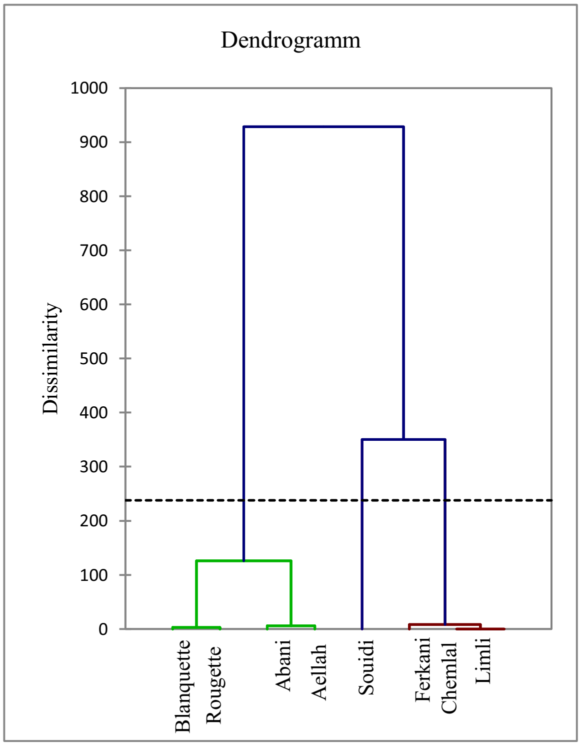

Fig. 2 Dendrogram of individuals according to the physical characteristics of fruits and stones

positive correlation was noted between protein and attack (0.743, $p < 0.05$). *Aellah*, *Limli* and *Rougette de Mitidja* are cultivars with similar contents and highest levels of protein (5.25%, 5.24 and 5.21%, respectively). Losses in protein are very distinctive among cultivars, varying from 14% in *Aellah* to 81% in *Abani*. Conversely, a different behavior was noted in *Ferkani* cultivar, without changes in protein levels. Our results agree those of Garantonakis et al. (2016) who noted a decrease in the fruit N content in six out of seven cultivars studied.

Olive pulp from the studied cultivars showed high contents of ash, ranging from 3.34% (*Rougette de Mitidja*) to 5.48% (*Blanquette de Guelma*). This parameter, is influenced by *B. oleae* attack, with losses since 13% in *Chemlal* to 42% in *Blanquette de Guelma*. It seems interesting to note that *Rougette de Mitidja* is the cultivar with the lowest level of ash and, according to the results presented in Table 2, do not suffered any damage with the fly attack. Garantonakis et al. (2016) showed that *B. oleae* infestation was positively correlated with K and Fe content. Significant changes in the concentration of P, K, Fe and Mg in fruits were also noted.

The energy determined in the samples varied among 567 kcal/ 100 g in *Chemlal* and 747 kcal /100 g in *Ferkani*, reflecting the nutritional potential of the olive fruits. Losses did not exceed 33% in all of cultivars, with a maximum recorded in *Blanquette de Guelma,* followed by *Limli* and the *Souidi* (32.42%).

Few studies have been done on the nutritional value of black olives. However, none has been devoted to the influence of the *B.oleae* fly on their nutrient levels. The statistical analysis showed a significant difference

Table 2 Protein, ash, lipids, carbohydrates and energy content of eight olive varieties

Variety	Attack (%)	Total Lipids (%)	Protein (%)	Carbohydrates (%)	Ash (%)	Energy (kcal)
Abani	**S (0)**	57.04 ± 0.30 jkl	3.47 ± 0.029 abc	39.49 ± 0.28 i	3.48 ± 0.1409 a	675.34 ± 1.59 j
	N (34.67)	52.23 ± 0.10 hi	1.62 ± 0.01 abc	39.31 ± 0.10 i	3.14 ± 0.05 a	623.96 ± 0.50 h
	A (100)	44.85 ± 0.04 f	0.67 ± 0.67 a	31.88 ± 0.64 efg	2.75 ± 0.17 a	525.91 ± 0.02 d
Aellah	**S (0)**	61.05 ± 0.87 lmn	5.25 ± 0.01 c	33.70 ± 0.88 efghi	4.40 ± 0.16 ab	696.84 ± 4.57 jk
	N (51.33)	54.49 ± 0.18 hij	4.60 ± 0.00 bc	28.80 ± 0.18 cde	4.03 ± 0.14 ab	616.79 ± 0.96 h
	A(100)	51.80 ± 0.14 h	4.50 ± 0.00 bc	29.37 ± 0.14 de	3.47 ± 0.01 a	594.32 ± 0.71 g
Blanquette de Guelma	**S(0)**	58.96 ± 0.17 klm	4.36 ± 0.86 bc	36.69 ± 0.69 hij	5.48 ± 0.50 ab	685.61 ± 0.67 j
	N (59.0)	53.56 ± 0.91 hij	2.40 ± 0.80 abc	35.36 ± 0.11 fghi	5.29 ± 0.96 ab	624.21 ± 4.56 h
	A 100)	34.34 ± 0.23 cd	1.91 ± 0.62 abc	37.84 ± 0.85 hi	3.18 ± 0.08 a	458.63 ± 1.35 b
Chemlal	**S(0)**	36.41 ± 0.61 d	4.38 ± 0.87 bc	59.21 ± 1.48 k	5.13 ± 0.08 ab	567.26 ± 3.41 f
	N (21.33)	32.18 ± 0.39 bc	4.01 ± 0.81 abc	55.21 ± 1.20 k	7.45 ± 0.81 b	512.68 ± 2.26 d
	A (100)	29.87 ± 0.34 b	3.52 ± 0.70 abc	47.31 ± 1.04 j	4.44 ± 0.02 ab	460.36 ± 1.96 b
Ferkani	**S (0)**	70.66 ± 0.27 o	3.50 ± 0.01 abc	25.85 ± 0.26 bcd	5.37 ± 1.17 ab	746.82 ± 1.41 l
	N (44.67)	61.00 ± 0.21 mn	3.09 ± 1.55 abc	24.36 ± 1.35 abc	6.06 ± 2.40 ab	652.71 ± 0.69 i
	A (100)	55.48 ± 0.49 hijk	3.22 ± 0.01 abc	21.02 ± 0.50 a	3.74 ± 0.57 a	594.98 ± 2.57 fg
Limli	**S (0)**	63.26 ± 0.362 n	5.24 ± 0.00 c	31.50 ± 0.36 ef	4.31 ± 1.09 ab	708.42 ± 1.90 k
	N (41.33)	58.36 ± 0.26 klm	4.02 ± 0.80 abc	29.81 ± 0.53 de	3.32 ± 0.04 a	653.14 ± 1.18 i
	A (100)	48.00 ± 2.26 g	3.40 ± 0.67 abc	26.15 ± 2.93 bcd	2.81 ± 0.05 a	543.61 ± 12.03 e
Rougette de Mitidja	**S (0)**	59.29 ± 0.60klm	5.21 ± 0.00 c	35.49 ± 0.60 fghi	3.34 ± 0.08 a	687.60 ± 3.17 j
	N (65.33)	55.89 ± 0.04 ijk	4.38 ± 1.18 bc	31.22 ± 1.22 ef	3.01 ± 0.14 a	637.59 ± 0.50 hi
	A (100)	40.17 ± 0.15 e	2.91 ± 0.59 abc	23.76 ± 0.74 ab	3.56 ± 0.46 a	462.29 ± 0.94 b
Souidi	**S (0)**	41.45 ± 0.212 e	2.62 ± 0.88 abc	55.92 ± 1.08 k	4.01 ± 0.11 ab	593.29 ± 1.30 fg
	N (21.00)	33.69 ± 0.27 cd	1.09 ± 0.36 ab	48.74 ± 0.09 j	2.93 ± 0.06 a	490.38 ± 1.35 c
	A (100)	24.46 ± 3.40 a	0.63 ± 0.00 a	47.55 ± 3.40 j	2.57 ± 0.03 a	400.95 ± 17.84 a

Different letters within each column indicate a significant difference ($P < 0.05$)

The results are arranged in ascending order; a < b < c < d < e < f < g < h < i < j < k < l

($p < 0.05$) between healthy and attacked samples, due to the pulp fruit consumption by the larvae.

Principal Component Analysis (PCA) was applied to evaluate the variability between olive samples regarding their nutritional value. As shown in Fig. 3, PCA results indicate that two factors account for 81.52% of the total variance (F1: 55.78%, F2: 25.73%).

The first factor was positively correlated with total lipids (0.962), protein (0.743) and subsequently with energy (0.928), and negatively with carbohydrates (−0.608). The second axe was positively correlated with ash and carbohydrates. The individualization of samples, according to the analyzed subjects, resulted in a great variability. It is clear the division of the samples into three groups essentially based in their opposed richness in lipid and proteins as well as carbohydrates content.

Within the same cultivar, the healthy and attacked samples are opposed, but also showed a significant difference in the constituent susceptibility of the different cultivars. *Aellah*, *Chemlal* and *Ferkani* are the cultivars less affected, presenting the healthy and attacked samples classified in the same group (Fig. 4).

Conclusion

The olive fruit fly *B. oleae* is responsible for an intensive damage in olive drupes, with negative repercussions in production, quality and economic levels. Concerning the pomological characteristics, larger fruit cultivars seems to be more affected. This is the case of *Rougette de Mitidja,* which has the highest percentage infestation among the studied varieties (65.33%). The highest susceptibility to the attack is related to the involvement of fruit size in the mechanism underlying the ovipositional preference and reproduction success of *B. oleae*. The pest strongly affects the nutritional value of the attacked olives. Losses in protein, carbohydrates, fat and energy are significant. The results of PCA and HCA showed a difference in the susceptibility of the constituents of the different cultivars. *Abani*, *Aellah*, *Rougette de Mitidja* and *Ferkani* are classified in the same group, which shows a very close behavior towards the attack. Oppositely, the other varieties are dispersed into different groups.

The attack was positively correlated with lipids and proteins content suggesting an involvement of these nutrients in ovipositional preference of olive fruit fly, which requires a deeper exploration of this fraction. To isolate and identify the different microorganisms that are associated with olive fruit infested by *Bactrocera oleae,* it is important to evaluate their ability to hydrolyze the olive components. Thus, the exploration of the phenolic compounds profile is also important as they might be implicated in longevity or death of the olive fly. It should be also highlighted that the maturation process

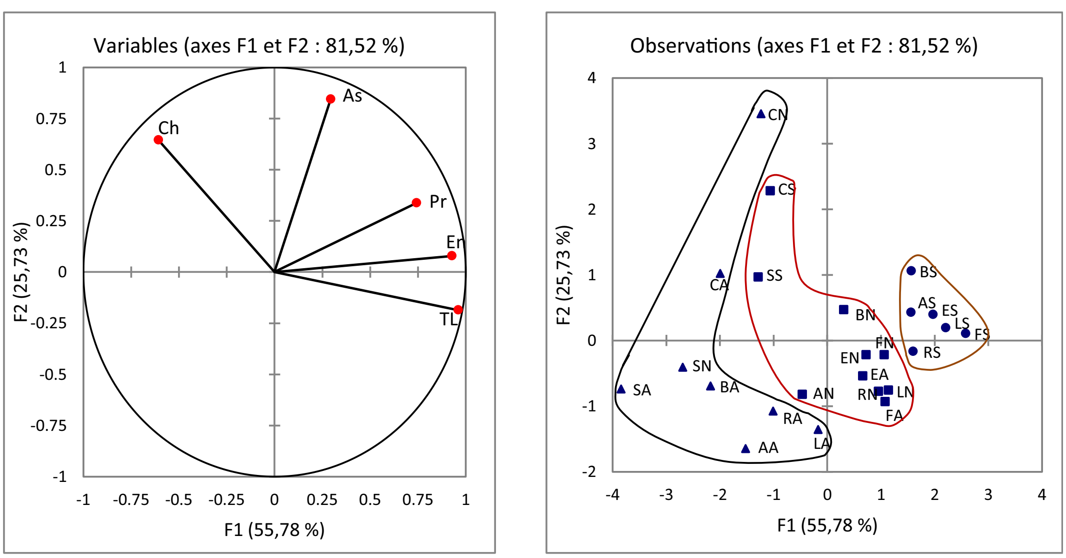

Fig. 3 Representation of the observations on the factorial plans 1–2 of the ACP from nutritional parameters. TL: total lipids; Pr: protein; En: Energy; Ch: carbohydrates; As: Ash. Varieties (first letter): *Abani* (A), *Aellah* (E), *Blanquette de Guelma* (B),*Chemlal* (C), *Ferkani* (F), *Limli* (L), *Rougette de Mitidja* (R), *Souidi* (S). State of olives (second letter), S: healthy olives, N: natural (reflecting the real attack rate of the fruit, A: only attacked olives

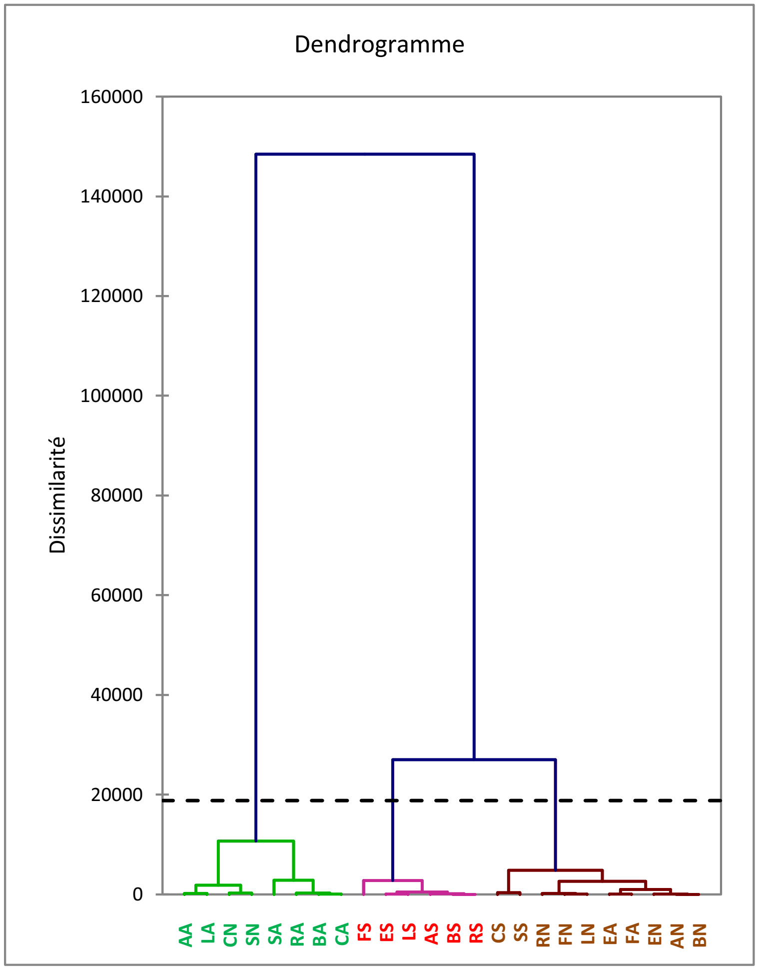

Fig. 4 Dendrogram of individuals according nutritional value. Varieties (first letter): *Abani* (A), *Aellah* (E), *Blanquette de Guelma* (B), *Chemlal* (C), *Ferkani* (F), *Limli* (L), *Rougette de Mitidja* (R), *Souidi* (S). State of olives (second letter), S: healthy olives, N: natural (reflecting the real attack rate of the fruit, A: only attacked olives

is the most influential factor for the internal and external changes of the olives of each cultivar. For this reason, as a future perspective, it must be explored. Therefore, ovipositional preference of olive fly females and the success of larval development in different olive cultivars are crucial to establishing new olive orchards that combine superior productive traits, e.g., oil yield and quality, and prevent high olive fruit fly infestation.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest. This article does not contain any studies with human or animal subjects.

References

Afellah, M., Smaili, C., Ben Hammadi, I., Hilal, A., & Chemseddine, M. (1997). Influence de la variété et du type de piège sur la courbe des vols de la mouche de l'olive *Bactrocera oleae* Gmel. dans la région de Ain Taoujdate au Maroc. *Ecologia Mediterranea A, 23*, 57–64.

Al-Salti, M. N., Edriss, O., & Al-ali, M. (2011). Susceptibility of two olive varieties Aldeibli and Alkhudairi to olive fruit fly *Bactrocera oleae* (Gmelin) (Diptera: Tephritidae). *Journal of Agricultural Science and Technology, 1*, 987–996.

Antonelli, R., & Chesi, F. (1985). Relation between some physical variables and the probability of olive fruit fly infestation on drupe of the var. Frantoio. *Frustula Entomologica, 8*, 601–611.

AOAC. (2012). *Official methods of analysis of AOAC international, 19 th edition, AOAC* (p. 53). USA: International, Gaithersburg, Maryland.

Athar, M. (2005). Infestation of olive fruit Fly, *Bactrocera oleae*, in California and taxonomy of its host trees. *Agriculturae Conspectus Scientificus, 70*, 135–138.

Ben-Yosef, M., Pasternak, Z., Jurkevitch, E., & Yuval, B. (2015). Symbiotic bacteria enable olive fly larvae to overcome host defences. *Royal Society Open Science, 2*, 150170.

Bueno, A. M., & Jones, O. (2002). Alternative methods for controlling the olive fly, *Bactrocera oleae*, involving semiochemicals. *IOBC/WPRS Bulletin, 25*, 147–156.

Capuzzo, C., Firrao, G., Mazzon, L., Squartini, A., & Girolami, V. (2005). Candidatus Erwinia dacicola, a coevolved symbiotic bacterium of the olive fly Bactrocera oleae (Gmelin). *International Journal of Systematic and Evolutionary Microbiology, 55*, 1641–1647.

Corrado, G., Alagna, F., Rocco, M., Renzone, G., Varricchio, P., Coppola, V., Coppola, M., Garonna, A., Baldoni, L., Scaloni, A., & Rao, R. (2012). Molecular interactions between the olive and the fruit fly *Bactrocera oleae*. *BMC Plant Biology, 12*, 1–17.

Daane, K. M., & Johnson, M. W. (2010). Olive fruit fly: Managing an ancient pest in modern times. *Annual Review of Entomology, 55*, 151–169.

Dag, A., Kerem, Z., Yogev, N., Zipori, I., Lavee, S., & Ben-David, E. (2011). Influence of time of harvest and maturity index on olive oil yield and quality. *Scientia Horticulturae, 127*, 358–366.

Edriss, O., Nammor, D., & Al Ali, M. (2008). The dynamic of development of olive fruit fly population *Bactrocera oleae* Gemlin (Diptera: Tiphritideae) in home province. *Journal of Al-Baath University, 30*, 395–313.

Garantonakis, N., Varikou, K., Markakis, E., Birouraki, A., Sergentani, C., Psarras, G., & Koubouris, G. C. (2016). Interaction between *Bactrocera oleae* (Diptera: Tephritidae) infestation and fruit mineral element content in Olea europaea (Lamiales: Oleaceae) cultivars of global interest. *Applied Entomology and Zoology, 51*, 257–265.

Genç, H. (2016). Infestations of olive fruit Fly, *Bactrocera oleae* (Rossi) (Diptera: Tephritidae), in different olive cultivars in Çanakkale, Turkey. *World Academy of Science, Engineering and Technology International Journal of Biological, Biomolecular, Agricultural. Food and Biotechnological Engineering (WASET), 10*, 439–442.

Gómez-Caravaca, A.M., Cerretani, L., Bendini, A., Segura-Carretero, A., Fernández-Gutiérrez, A., Del Carlo, M., Compagnone, D., & Cichelli, A. (2008). Effects of fly attack (*Bactrocera oleae*) on the phenolic profile and selected chemical parameters of olive oil. Journal of Agricultural and Food Chemistry, 56, 4577–4583.

Gonçalves, M. F, Malheiro, R., Casal, S., Torres, L., & Pereira, J. A. (2012). Influence of fruit traits on oviposition preference of the olive fly, Bactrocera oleae (Rossi) (Diptera: Tephritidae), on three Portuguese olive varieties (Cobrançosa, Madural and Verdeal Transmontana)". *Scientia Horticulturae,* 145, 127–135.

Grasso, F., Coppola, M., Carbone, F., Baldoni, L., Alagna F., Perrotta, G., Pérez-Pulido, A., Garonna, A., Facella, P., Daddiego, L., Lopez, L., Vitiello, A., Rao, R., Corrado, G. & Vontas , J. (2017). The transcriptional response to olive fruit fly (Bactrocera oleae) reveals extended differences between tolerant and susceptible olive (Olea europaea L.) varieties. PLoS One, 12, e0183050.

Gümusay, B., Özilbey, U., Ertem, G., & Oktar, A. (1990). Studies on the susceptibility of some important table and oil olive cultivars of Aegean region to olive fly (Dacus oleae Gmel.) in Turkey. *Acta Horticulturae, 286*, 359–362.

International Olive Council, (2011) The guide for the determination of oil-olives (COI/OH/doc. No 1) (2011).

International olive oil council IOOC, Olive oil, (2016) Table 1: production, November (2016).

Jiménez, B., Sánchez-Ortiz, A., Lorenzo, M. L., & Rivas, A. (2013). Influence of fruit ripening on agronomic parameters, quality indices, sensory attributes and phenolic compounds of Picudo olive oils. *Food Research International, 54*, 1860–1867.

Liscia, A., Angioni, P., Sacchetti, P., Poddighe, S., Granchietti, A., Setzu, M. D., & Belcari, A. (2013). Characterization of olfactory sensilla of the olive fly: Behavioral and electrophysiological responses to volatile organic compounds from the host plant and bacterial filtrate. *Jounal Insect Physiology, 59*, 705–716.

Malheiro, R., Casal, S., Baptista, P., & Pereira, J. A. (2015a). A review of *Bactrocera oleae* (Rossi) impact in olive products: From the tree to the table. *Trends in Food Science and Technology, 44*, 226–242.

Malheiro, R., Casal, S. R., Cunha, S. C., Baptista, P., & Pereira, J. A. (2015b). Olive volatiles from Portuguese cultivars Cobrançosa, Madural and Verdeal Transmontana: Role in Oviposition preference of *Bactrocera oleae* (Rossi) (Diptera: Tephritidae). *PLoS One, 10*, e0125070.

Medjkouh, L., Tamendjari, A., Keciri, S., Santos, J., Antónia Nunes, M., & Oliveira, M. B. P. P. (2016). The effect of the olive fruit fly (*Bactrocera oleae*) on quality parameters, and antioxidant and antibacterial activities of olive oil. *Food & Function, 7*, 2780–2788.

Medjkouh, L., Tamendjari, A., Alves, C. R., Laribi, R., & Oliveira, B. (2018). Phenolic profiles of eight olive cultivars from Algeria: Effect of: *Bactrocera oleae* attack. *Food & Function, 9*, 890–897.

Mesbah, H. A., & Megda, B. (1996). The insect pests of olive trees in Siwa Oasis with special reference to *Dacus oleae, Saissetia oleae* and certain beneficial insects. *Egyptian German Society of Zoology, 21*, 167–185.

Neuenschwander, P., Michelakis, S., Holloway, P., & Berchtold, W. (1985). Factors affecting the susceptibility of fruits of different olive varieties to attack by *Dacus oleae* (Gmel.) (Dipt., Tephritidae). *Z Angew Entomology, 100*, 174–188.

Pavlidi, N., Gioti, A., Wybouw, N., Dermauw, W., Ben-Yosef, M., Yuval, B., Jurkevitch, E., Kampouraki, A., Van Leeuwen, T., & Vontas, J. 2017. Transcriptomic responses of the olive fruit fly Bactrocera oleae and its symbiont Candidatus Erwinia dacicola to olive feeding. Scientific Reports 7, 42633.

Pimentel, F. B., Alves, R. C., Costa, A. S. G., Fernandes, T. J. R., Torres, D., Almeida, M. F., & Oliveira, M. B. P. P. (2014). Nutritional composition of low protein and phenylalanine-restricted dishes prepared for phenyl-ketonuric patients. *Entomologia Experimentalis et Applicata, 57*, 283–289.

Rizzo, R., Caleca, V., & Lombardo, A. (2012). Relation of fruit color, elongation, hardness, and volume to the infestation of olive cultivars by the olive fruit fly, *Bactrocera oleae*. *Entomologia Experimentalis et Applicata, 145*, 15–22.

Sacchetti, P., Granchietti, A., Landini, S., Viti, L., Giovannetti, L., & Belcari, A. (2008). Relationships between the olive fly and bacteria. *Journal of Applied Entomology, 132*, 682–689.

Scarpati, M. L., Lo Scalzo, R., Vita, G., & Gambacorta, A. (1996). Chemiotropic behavior of female olive fly (Bactrocera oleae Gmel) on Olea europaea L. *Journal of Chemical Ecology, 22*, 1027–1036.

Sharaf, N. S. (1980). Life history of olive fruit fly, *Dacus oleae* Gmel. (Diptera. Tephritideae) and its damage to olive fruits in Tripolitania. *Journal of Applied Entomology, 89*, 390–400.

Tamendjari, A., Angerosa, F., & Bellal, M. M. (2004). Influence of *Bactrocera oleae* infestation on olive oil quality during ripening of Chemlal olives. *Italian Journal of Food Science, 16*, 343–354.

Tamendjari, A., Sahnoune, M., Mettouchi, S., & Angerosa, F. (2009). Effect of *Bactrocera oleae* infestation on the olive oil quality of three Algerian varieties: Chemlal, Azzeradj and Bouchouk. *Rivista Italiana delle Sostanze Grasse, 86*, 103–111.

Tamendjari, A., Laribi, R., & Bellal, M. M. (2011). Effect of attack of *Bactrocera oleae* on olive oil by the quality of the volatile fraction of oil from two varieties Algerian. *Rivista Italiana delle Sostanze Grasse, 88*, 114–122.

Tzanakakis, M.E. (2006). Insects and mites feeding on olive: Distribution, importance, habits, seasonal development, and dormancy, applied entomology library Ed, brill, Leiden, Boston, 182 pp.

Wang, X. G., Johnson, M. W., Daane, K. M., & Yokoyama, V. Y. (2009). Larger olive fruit size reduces the efficiency of *Psyttalia concolor*, as a parasitoid of the olive fruit fly. *Biological Control, 49*, 45–51.