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Flight activity of *Bactrocera oleae* (Rossi, 1790) (Diptera: Tephritidae) infesting two Algerian olive varieties in north-west Algeria

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Abstract: *Bactrocera oleae* (Rossi, 1790) (Diptera: Tephritidae) is the most dangerous insect pest of the olive tree in the Mediterranean region. This study was conducted in the Mascara region (North-West Algeria) during 2019-2020 season, in order to monitoring the flight activity of *B. oleae* by using Mc Phail type traps and evaluating the infestation rate on two olive varieties (Sigoise and Chemlal) by fruits sampling. The data obtained indicated that the flight activity of *B. oleae* developed five peaks of the abundance. The General Linear Model (GLM) showed that infestation rate and fruit caliber varied considerably among varieties and across the sampling date, which gradually increased with time. 'Sigoise' having the highest caliber and was more infested than 'Chemlal'. The northern cardinal orientation of the tree was the least attacked by this pest. The GLM function showed that there was relationship between the infestation rate and fruit size.

Key words: *Bactrocera oleae*; flight activity; infestation; caliber; 'Sigoise'; 'Chemlal'

Let oljčne muhe (*Bactrocera oleae* (Rossi, 1790), Diptera: Tephritidae) na dveh alžirskih sortah oljke v severozahodni Alžiriji

Izvleček: Oljčna muha (*Bactrocera oleae* (Rossi, 1790), Diptera: Tephritidae) je najškodljivejša žuželčja vrsta na oljkah v Sredozemlju. Raziskava je bila izvedena na območju Mascare (severozahodna Alžirija) v rastni dobi 2019-2020, z namenom načrtnega spremljanja leta oljčne muhe z uporabo Mc Phailovih pasti in ovrednotenja stopnje napada dveh sort oljke ('Sigoise' in 'Chemlal') z vzorčenjem plodov. Pridobljeni podatki nakazujejo, da je imela oljčna muha pet vrhov pojavljanja. Splošni linearni model je pokazal, da sta se stopnja napada in debelina plodov znatno spreminjala glede na sorto in datum vzorčenja in sta s časom naraščali. Sorta Sigoise je imela najdebelejše plodove in je bila bolj napadena kot sorta Chemlal. Na sever orientirani deli krošenj so bili najmanj napadeni. Splošni linearni model je pokazal, da obstaja povezava med stopnjo napada oljčne muhe in debelino plodov oljk.

Ključne besede: *Bactrocera oleae*; aktivnost izletov; napadi; debelina plodov; 'Sigoise'; 'Chemlal'

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1 INTRODUCTION

Algeria is one of the main olive (*Olea europaea* L., Oleaceae) producing countries. In 2019 it took the ninth class in world olive production with a production of 868,754 tons on an area of 431,634 ha (FAO Stat, 2021). Algerian olive oil production was 90,000 tons in the 2020/2021 campaign. This crop is attacked by various pests and diseases. The olive fly *Bactrocera oleae* (Rossi, 1790) (Diptera: Tephritidae), is the most serious and economically harmful insect pest of commercial olive production worldwide (Ras et al., 2017; Torrini et al., 2020). This fly is multivoltine and homodynamic, i.e. their population dynamics, number of generations and the length of their life cycles depend mainly on the climate (temperature and humidity), but also vary according to other factors: geographic regions , availability and quality of olive fruits (Daane & Johnson, 2010; Malheiro et al., 2015; Pertíñez & Vélez, 2020). This pest causes the severe qualitative and quantitative damage, where economic losses can reach 100% due to uncontrolled infestation and oil losses of up to 80% (Rice, 2000; Genç & Nation, 2008; Zalom et al., 2009). Also, the formation of tunnels inside mesocarp and exit holes allowing the introduction of bacteria and fungi that rot the fruit and increase the acidity of the oil (Athar, 2005; Zalom et al., 2009). The infestation of olives caused by *B. oleae* varies greatly between years, regions and olive varieties (Goncalves et al., 2012). Gaouar and Debouzi (1991) found that the level of infestation was quite high near 100% in orchards close to the coast, in the province of Tlemcen (North West Algeria) on two local varieties (Sigoise and Chemlal). Other authors have also shown a fruit infestation level of up to almost 100% in Portugal (Bento et al., 2009) and in California (Burrak et al., 2011).

The preference and sensitivity of olive cultivars by the *B. oleae* vary by three factors: physical, chemical and molecular. The physical factor remains the most influencing, which includes size, mass, volume, fruit color and hardness of the exocarp (Malheiro et al., 2015). The female of *B. oleae* prefers to oviposite on cultivars with large, unripe olives (Neuenschwander et al., 1985). Several studies (Burrack & Zalom, 2008; Goncalves et al., 2012; Garantonakis et al., 2017; Medjkouh et al., 2018) have confirmed that the oviposition preference by the female *B. oleae* was positively correlated with the maturity index, mass and volume on the other hand oviposition was negatively correlated with the hardness of the exocarp.

The olive varieties studied 'Sigoise' and 'Chemlal' are two Algerian varieties renowned for their excellence in quality and productivity. In order to preserve the quantity and the marketable quality of these two varieties against the attacks of such a pest, it was imperative to determine its population dynamics and its infestation rates in relation to the size of the fruits than with the four cardinal orientations of the tree in the region of Mascara (North-West Algeria).

2 MATERIAL AND METHODS

2.1 STUDY AREA

This study was carried out in Oued Taghia region at an altitude of 471 m (35 ° 6 '35 "N, 0 ° 5' 19" E) in the province of Mascara (North-West of Algeria), during the

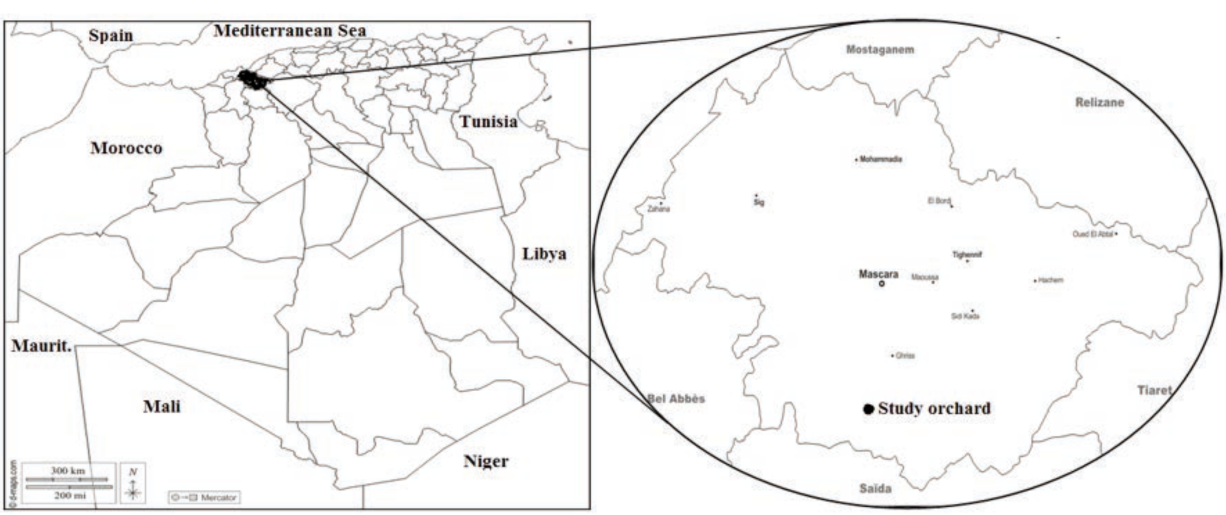

Figure 1: The geographical localization of study area (Mascara: Algeria) and the situation of study orchard

Figure 2: The study orchard (Oued Taghia, Mascara)

period that extends from June 2019 to April 2020. The study region is characterized by a semi-arid, dry and cold climate, far from the sea by a distance of about 120 km (Figure 1). The olive orchard has been planted with two varieties, Sigoise (intended for the production of table olives) and Chemlal (intended for the production of oil). The trees were medium in size, about 16 years old, and were spaced about 10 m × 8 m, being irrigated artificially by gravity and pruned bi-annually. The olive orchard has not received any treatment against diseases and pests for the past three years, but chemical fertilizers are applied every winter (Figure 2).

2.2 SAMPLING METHODOLOGY

The flight activity of adults of *B. oleae* was monitored using 4 plastic Mc Phail traps with a transparent upper half and a yellow lower half, baited with a 3 % aqueous solution of di ammonium phosphate which is attractive to both sexes. The traps are installed at the beginning of June 2019. The solution has been renewed every 10 to 20 days. The traps were tied under the shade of the branches inside the foliar crown in the southwest direction of the tree, at a human height. The traps were distributed randomly in the olive orchard with 50 m distance between them. Which were checked every 10 days and the olive flies were counted, sexed and removed. The total number of individuals captured in the McPhail traps was used to estimate the population index (Pi) which was expressed as the total number of captures per trap per day in each date (Goncalves et al., 2012). Sex ratio was estimated by the ratio (male / total and female / total).

Every 10 days, from the appearance of the first stings (beginning of September which corresponds to the slight drop in temperature and after the setting of the olives) until the harvest (end of December), fruit samples were taken from 5 trees of each variety of olive tree, to assess the infestation rate of the olive tree and the size of the fruit. 40 olives per tree were harvested at head height from 4 cardinal orientations of each tree (north, south, east, and west), due to 10 olives for each orientation. The olives collected were brought to the laboratory and were observed under a binocular stereo-microscope (EUROMEX, The Netherlands) to check for the presence of oviposition stings and exit holes insect. The *B. oleae* infestation rate was expressed as a percentage of the infested olives relative to the total number of olives collected. According to Burrack et al. (2011), olives with oviposition stings were considered infested.

To estimate the caliber of the fruit, 50 olives were chosen by chance for each variety (10 olives per tree). Using a digital caliper (OEM, China), the widest dimension was measured in mm.

2.3 DATA ANALYSIS

The statistical software SPSS (version 21) was used to analysis the data on infestation rate and fruit caliber with General Linear Model (GLM): Repeated Measures with "variety" and "sampling date" as effects. ANCOVA was used to study the effect of cardinal orientation on infestation rate in both varieties. Tukey post-hoc test was applied to compare the infestation rate of different cardinal orientations. The GLM function in R environment (R Core Team, 2021) was used to build the relation between the infestation rate and the fruits caliber. The significance level for all analyses was 0.05.

3 RESULTS

3.1 POPULATION DYNAMICS OF THE OLIVE FLY AND ENVIRONMENTAL CONDITIONS

Olive fly flight activity was distributed throughout the year (Figure 3). The dynamic of adult flights was showed five major peaks, which correspond to the number of generations. The first flies in our study area were captured on 23/06/2019 with a Pi population index of 0.12 flies / trap /day. So that, the first peak appeared on 13/07/2019. From this date, the number of individuals decreased and coincided with the increasing in temperature and the falling in humidity (summer period). In September, the population returns to increase relatively with the decreasing in temperature and the increasing in humidity, forming a succession of 3 autumn-winter generations; September 03 (0.70 flies / traps / day), November 03 (2.4

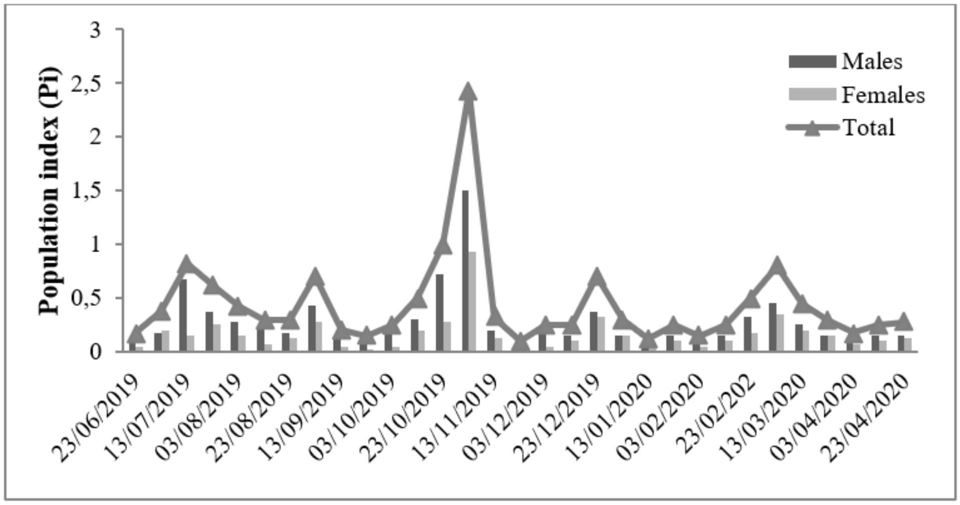

Figure 3: Population indexes Pi (total, male and female), during the study period

flies / traps / day), December 23 (0.70 flies / traps / day) respectively. The value of the population index decreased from the end of December to February, where the temperature in this period is ≤ 10 °C which corresponds as a limiting factor (Fig 3 and 4). The 5th generation is spring generation that appeared at 03/03/2020 (0.80 flies / traps / day). The sex ratio of captured flies was constantly in favor of males (0.63 males and 0.37 females).

3.2 INFESTATION RATE

Infestation rate differed significantly between varieties and across the sampling date as well as the interaction of them (Table 1). Infestation rate of 'Sigoise' was higher than that of 'Chemlal' (Figure 5). At the beginning of September, the infestation rate was low (11.50 ± 1.66 %, 7.00 ± 1.27 %) respectively for the two varieties Sigoise and Chemlal. As of October 03, the infestation increased for 'Sigoise' variety, while for 'Chemlal', the increase of the infestation was moderate. In December, the infestation in 'Chemlal' was intensified and reached high value at the time of harvest (78 %), which is near to 'Sigoise' infestation rate (84 %) (Figure 5).

Fruit calibers differed significantly among varieties, the sampling date and the interaction between the two factors (Table 1). The fruit caliber was higher in 'Sigoise' than 'Chemlal' throughout the study period. We noted a rapid increase of caliber in 'Sigoise' variety and a slight increase in 'Chemlal' variety (Figure 6).

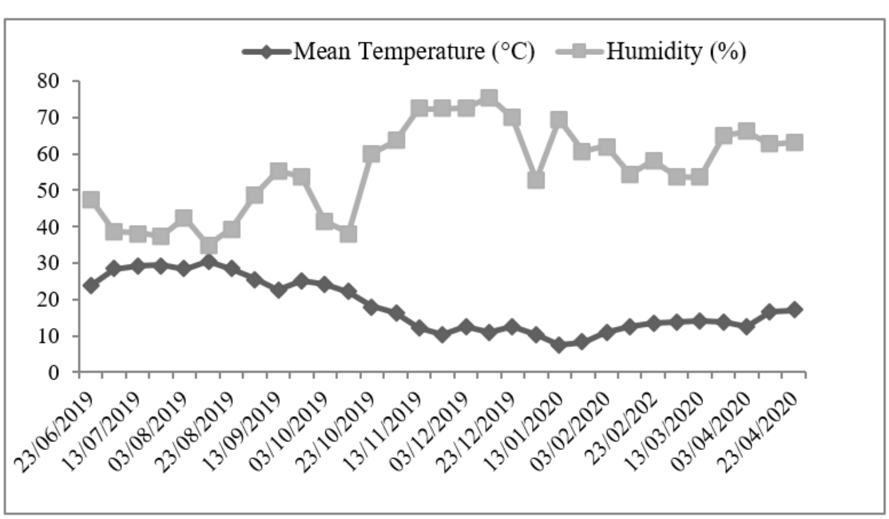

Figure 4: Average daily data of the temperature and relative humidity from June 23, 2019 to April 23, 2020 in the Mascara region

Table 1: Effects of variety and sampling date on infestation rate and fruits caliber for the year 2019 (GLM: Repeated measures)

Variable	Factor	*df*	*F*	*p*
Infestation rate	Sampling date	6.46	238.02	<0.0001
	Variety	1	26.28	<0.0001
	Interaction	6.46	7.79	<0.0001
Fruit caliber	Sampling date	10.16	295.62	<0.0001
	Variety	1	1743.06	<0.0001
	Interaction	10.16	49.87	<0.0001

In order to study the influence of the fruit size factor on both varieties susceptibility to *B. oleae*, a relationship was estimated between the infestation rate and the caliber of the fruits by the GLM function in R (R Core Team, 2021). The results showed that size coefficient is highly significant (p <0.001), while the variety coefficient is not significant (p = 0.14). This mean that the infestation rate is not linked to the variety but to the size. The relation is written in the following form:

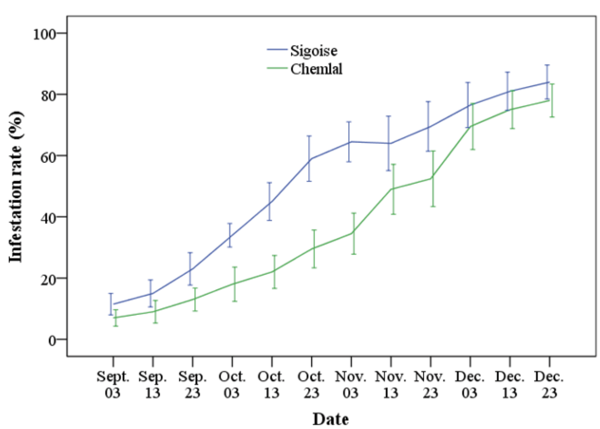

Figure 5: Infestation rate (mean ± S.E) of the two varieties by the olive flies (September to December 2019)

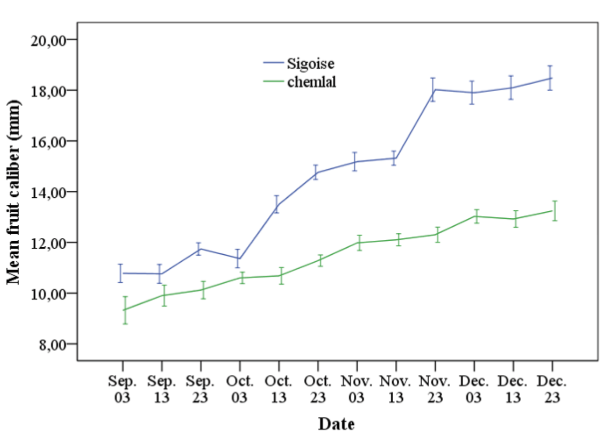

Figure 6: Mean fruit caliber (mean ± S.E) of the two varieties by the olive flies (September to December 2019)

$$Infestation\ rate = -15.414 + -2.32 * Variety + 5.17 * Size \quad (1)$$

On the other hand, ANCOVA analysis revealed that there is a significant difference of the infestation between the cardinal orientations of the tree throughout the study period ($F = 44.03$, $df = 3$, $p = 0.006$) and between varieties ($F = 111.28$, $df = 1$, $p = 0.002$), while their interaction did not found significant for infestation ($F = 0.29$, $df = 3$, $p = 0.83$). Posthoc tests of Tukey's confirmed that the North direction is the least infested by the olive fly in both varieties, but there is no significant difference between other orientations (East, South and West) (Figure 7).

4 DISCUSSION

4.1 STUDY OF THE POPULATION DYNAMICS OF THE OLIVE FLY

The presence and fluctuation of the fly throughout the year are well demonstrated by our results with an important number of generations (five peaks per year), this latter depends on several factors, mainly the climate which is closely linked to the longevity of this pest, fruits

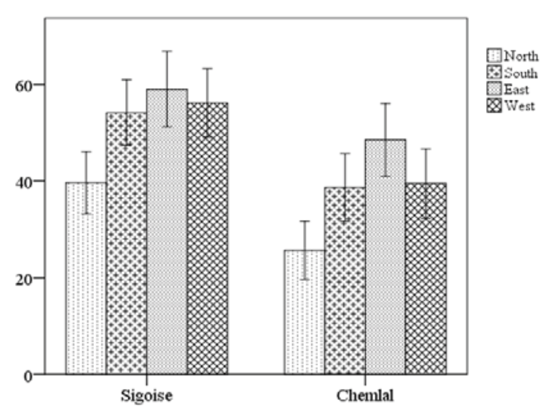

Figure 7: Variations in the infestation rate (mean ± E.S) of olives in relation to cardinal orientation of the tree throughout the study period

damaged which remain after harvest which ensures the maintaining and continuity of the species in the orchards (Jimenez et al., 1994). Daane & Johnson (2010) claim that even if the olive tree is unsuitable for oviposition, adults have the ability to reproduce and survive when their nutrition is available, which constitutes a true danger to olive orchard.

In the study area, the first generation was reported in July. Also, Gaouar (1996) in the Tlemcen region in Algeria, Yokoyama et al. (2006) in southern California, Goncalves et al. (2012) in Portugal, Ait Mansour et al. (2015) in Morocco and Pertíñez & Vélez (2020) in Madrid (Spain) found a generation was marked at the end of June or the beginning of July in the olive orchards close to the sea (fresh and humid), however in inland areas which far of coastline, the summer generation was absent. This can be explained by the hot, arid conditions and the unavailability of fruit. We reported the second generation on September 03, 2019 where the temperature and humidity conditions become ambient also the receptive olives are available and premature. It was followed by the third at the beginning of November and the fourth at the end of December. This succession of three generations in the autumn was similar to the results of Goncalves et al. (2012) and Ait Mansour et al. (2015). However, Gaouar (1996) and Yokoyama et al. (2006) found two generations in this period and Pertíñez & Vélez (2020) found only one generation in the fall. This overlap of generations was explained by the contribution of each generation to the coexistence of the future generation. The fourth generation in our result was absent in most of the studies, this can be explained by the late harvest of the fruits until the end of December. Generally according to several researchers, in most regions, autumn is the season best suited to the development of the olive fly, when its larval food is available (Daane & Johnson, 2010). Besides, Yokoyama et al. (2006) explained that the unusually large number of adults captured from March to April is due to the presence of fruits in the orchard of the previous year, which provides oviposition sites and food for the development of this pest. This ascertainment explains well and justifies the appearance of the fifth generation (March 03, 2020) in our study region. Also, the population density is closely related to climatic conditions (temperature and humidity). According to Marchi et al. (2016), interannual variations of the population are explained by temperature and according to Broufas et al. (2009) Relative humidity can lead to increased longevity of the fly and the fertility of their females. Concerning the study of the sex ratio, it was noticed from the results that the number of catches of males was greater than that of females (0.63 males and 0.37 females), this can be justified by the color yellow traps and nature of bait. This ascertainment is similar to that of Katsoyannos & Kouloussis (2001) who explain that catches are strongly influenced by the color of the traps, where he reported that males of olive flies are attracted to the yellow, orange and white color traps, while females by the colors red and black. Rice et al. (2003) revealed that traps baited only with ammonium bicarbonate, more male than female flies were collected.

4.2 INFESTATION RATE

The fruit infestation started on September 03, 2019 where the olives reached the fruit enlargement and stone hardening stage, which is considered the receptive stage for oviposition olive fly (Civantos, 1999), thus coinciding with the period of ovarian maturation of females (Tzanakakis, 2003). Our results are similar to those of (Ibnsouda et al., 2004; Goncalves et al., 2012). The significant increase of the infestation over time was justified by the increase in the number of captures. Pertíñez & Vélez (2020) mentioned that the proportional increase of damage was caused by the increase of the population size, while all reductions in population size maintained the total amount of damaged olives. The study of the influence of the cardinal orientation of the tree on the level of infestation revealed that the northern cardinal orientation of the tree is less attacked by the fly, according to Goncalves et al. (2012) the olive fly prefers to oviposite on the coldest areas of the tree. While Gaouar & Debouzi (1991) indicated that the cardinal orientation in olive trees did not influence the infestation.

Not only the number of captures by olive flies is responsible for of the damage importance to the olive tree, but also the different aspects of cultivars play an important role in their susceptibility to oviposition. The olive flies preference for oviposition appears to lie in the interaction and correlation of three aspects: physical, chemical and molecular (Malheiro et al., 2015). Certain physical characteristics of fruits including color, elongation, hardness and volume affect their susceptibility to this pest (Rizzo et al., 2012). Several studies have evaluated a good correlation between fruit size and olive tree infestation (Neuenschwander & Michelakis, 1979; Burrak & Zaloum, 2008; Rizzo et al., 2012; Garantonakis et al., 2017; Medjkouh et al., 2018). We have reported in our case that there is an important relationship between fruit size and infestation rate. The difference between the infestations of the two varieties was justified by the sensitivity of the table variety (Sigoise) which has a larger size than that of the 'Chemlal' variety with small fruits and high oil content, where this latter is less infested. Our results are in agreement with those of Jerraya et al. (1982), Arambourg (1984) and of Gaouar & Debouzi (1991). A similar infestation rate in the two varieties studied was observed at the end of the season (84.00 ± 2.65 % 'Sigoise', 78.00 ± 2.57 % 'Chemlal'), despite that the fruits calibers are different (18.48 ± 0.24 mm for the 'Sigoise' and 13.24 ± 0.19 mm for 'Chemlal'). These rates which seem the same important mark the third generation with a number of adults which reaches its maximum (2.4 flies / traps / day), we can say that the adults of this generation could oviposite their eggs in almost all the fruits not infested (regardless of caliber) (Gaouar & Debouzi, 1991).

5 CONCLUSION

The trapping of the olive fly adults allowed us to determine their population dynamic and to evaluate the number of generations in Mascara region, this pest is present throughout the year with five generations. The overlapping of the autumn generations causes important damage to the olives. The evaluation of the infestation rate showed that at the beginning of the season, the olives of the Sigoise variety are more attacked by *B. oleae* than the olives of 'Chemlal'. This difference remain linked to the size of the fruits, where the Sigoise variety had large caliber olives (table variety) compared to the small-fruited Chemlal variety (olive intended for oil). However, at the end of the season, despite the two varieties were different in the size of their olives, but the infestation rate is high for both.

The knowledge the dynamics of *B. oleae* populations and the determination the level of infestation that can inflict on different olive varieties remains the key to obtain better integrated control strategy against such parasites in an area as important as Mascara (Algeria) recognized by its olive vocation and its national and international fame.

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