Research Article

Reduction of olive fruit fly damage by early harvesting and impact on oil quality parameters

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Olive fly population was monitored weekly on two olive cultivars (*Buža* and *Istarska bjelica*), from June until mid October, in Rovinj and Livade (Istria, Croatia). The number of eggs, larvae, and pupae was established and the total and active infestation was calculated. The fruit infestations for early and for late harvesting were obtained based on the calculated regression equation. For the prediction of the changes in the oil quality parameters linear regression slopes, obtained by Koprivnjak et al., were used. We established a strong positive correlation between DD accumulation and cumulative capture of flies, as well as with the total and active fruit infestations. According to obtained results it can be stated that *I. bjelica* is less sensitive to decrease in total phenols amount, to increase in free fatty acids mass ratio and to increase in peroxide values comparing to *Buža*. Moreover, the differences in investigated parameters between earlier and late harvesting dates in *I. bjelica* are lower due to lower infestation predicted for both harvesting dates and due to lower sensitivity to the changes in quality parameters. Therefore, early harvesting date as a model for preventing fruit damage and as a model for preventing negative change in oil quality parameters is a valid tool. However, the effectiveness of this model could also depend on the characteristics of olive cultivar.

Practical applications: Understanding the factors that affect the olive fly attack is the basis of scientific and practical interest in the production of olives and olive oil. Research of monitoring methods allows reliable forecasting and determining protection measures. Knowledge about this topic could contribute to the reduction of insecticides use and to the improvement of quality and food safety concept in olive oil production.

Keywords: *Bactrocera oleae* / Infestation / Harvest / Olive fruit fly / Olive oil quality

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1 Introduction

The olive fruit fly (*Bactrocera oleae* Gmelin) is the most serious insect pest of olive fruits from the economic aspect [1–3]. It is present in all olive growing areas in the Mediterranean countries [4]. Adults prefer to feed on nectar, honey dew, and other opportunistic sources of liquid or semi-liquid food [5]. The larvae feed on mesocarp tissue, boring galleries inside the fruit, and allowing infestations of bacteria and fungi [6]. The damage caused by larvae feeding inside the fruit may be affected by: premature fruit falling (losses 20–80%), reducing the olive fruit weight (50–270 mg/olive fruit) and olive oil content (10–15%), and poor quality of olive oil [1, 7–10]. Numerous authors have reported on the influence of olive fly attack on the increase of oxidative and hydrolytic degradation of oil inside the fruit [1, 11–14]. The same has been reported for oxidative and hydrolytic degradation of phenolic compounds [1, 15, 16] as well as for the appearance of off flavors as a consequence of microorganisms' activity [17–19]. Even with the pesticide treatments that are applied every year to control the olive fruit fly population, the damage, caused by this insect in the fruits, results in about 10–30% of olive crop loss [20–22]. Without treatment and under optimum climate

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Abbreviations: DD, degree day; **FFA,** free fatty acids; **EV,** extra virgin

conditions, for the development of the olive fruit fly, the insect could infect up to 100% of the olive fruits [6]. The impact of this damage, however, can vary considerably, depending on whether the fruit is used for oil extraction or for table consumption. Fruits destined for oil extraction can be affected by a higher level of infection than those intended for table consumption. Therefore, it is very important for those fruits to be reaped in a relatively short time (3–4 wk) after the larvae begin feeding inside the fruit and when those fruits are immediately processed to limit further damage [4, 10, 13, 17, 19].

The life cycle of the olive fruit fly is closely related to the development of the host plant, the cultivated olive tree (*Olea europea* L.) and favorable climate conditions, mainly temperature, rainfall, and relative humidity [23]. In Croatia, the olive fruit fly develops 3–4 generations per year and all cause damage into the fruit [1, 24]. Population dynamic in Sardinia is characterized by two peaks, a smaller peak in spring (April–May) with the adults emerging from the overwintering generation, and more important, a higher peak at early autumn (September–October) when the olives show the highest level of receptivity, the temperature slightly decreases, and the weather becomes rainier [25]. In most cases, the greatest damage occurs as the fruit begins to soften and turns color, from September to November. Olive fruits that are left on the tree, that are not harvested or are left to fall naturally, and then processed to oil, also affect the activity of olive fruit flies in the period from late autumn to early spring [4, 26].

Numerous studies [2, 5, 18, 26–29] reported that the model of the early harvest reduces infection and damage of the olive fruit fly at the most possible lowest level. Optimal harvesting time is the most important factor that determines the olive oil quality and quantity [30, 31]. That can be a successful protection measure against the olive fruit fly, especially for susceptible olive cultivars. Some authors reported that in years with a strong olive fly attack, harvesting should be done 2 wk earlier in order to prevent the fruit yield loss [27]. Olive fruit development and ripening depends on the cultivar characteristics and environmental differences for each olive growing area [5, 31, 32]. Moreover, it is known that olive fly attack usually induces the fruit ripening process. From Roman times, it has been known that in the Istrian peninsula olive oil was obtained from green to yellow-green colored fruits [2]. In the northern areas of cultivation, olive fruit doesn't mature completely, and the optimal harvesting period is considered to be at the point when the fruits color is in 1:3 black and 2:3 green [2].

The beginning of the harvesting period in the Istrian peninsula overlaps with the second peak of the olive fruit fly. It is necessary to investigate the validity of pesticide application, or to explore the possibility of using the early harvest model to protect the olive fruit from the olive fruit fly attack. In order to understand better how the increase of fly population influences the fruit infestation over the time, two specific olive cultivars from two different localities were chosen. *Istarska bjelica* (synonyms *Istarska belica* or *Bianchera istriana)* and *Buža* (synonym *Busa*) are autochthonous cultivars of the Istrian peninsula, an area shared by Croatia, Slovenia, and Italy. The first cultivar is characterized by a lower flesh/stone mass ratio (6.87), oval fruit shape, and late ripening, while the second one has spherical fruits of somewhat higher flesh/stone mass ratio (8.24) and earlier ripening [33, 34]. Both cultivars are susceptible to olive fruit fly attack [35]. The next question is how increasing levels of mechanical damages caused by olive fruit fly attack could reflect on olive oils qualitative properties. The infestation of fruits is expected to be lower at earlier harvesting which will reduce the negative impact of damage on the oil quality parameters.

2 Materials and methods

The investigation was conducted in 2009 in two olive orchards located in Rovinj (45°7'20''N/13°38'1''E; elevation 15 m) and Livade (45°22'7''N/13°50'58''E; elevation 190–250 m). The orchard located in Rovinj (Valalta) was planted with the olive cultivar *Buža* while at the locality of Livade (Ipši) the olive cultivar *I. bjelica* was planted.

Olive fruit fly population was followed by two types of traps, yellow sticky trap baited with pheromone (YST + Ph, Serbios) and by McPhail trap (MPhT) trapped by 3% hydrolyzed protein. Both traps were placed in June at each locality. Every 7 days traps were inspected, the captured flies were counted and removed from the traps. Traps were changed regularly, every 5 wk. The last trap inspection was conducted at locality Rovinj on October 13th and at locality Livade on October 19th. For each trap type and each locality capture of the flies was calculated as cumulative capture. After the first capture of flies, once per week, four fruit samples (each containing 100 fruits) per locality were surveyed on presence of eggs, larvae, and pupae. For each sampling date the average number of eggs, larvae and pupae was established and the active (L2, L3, and pupae) and total infestation were calculated. For calculating active infestation a modified method described by Iannotta et al. [36] was used, considering that in the Istrian peninsula, especially during the summer period, eggs and L1 larvae mortality are influenced by high temperatures [37–39]. There is also the problem of egg identification. Moreover, to determine persistence of dead eggs and larvae, especially during fruit ripening period [37] is also another important issue.

Climatic data on mean average daily temperatures and rainfall were collected from the nearest meteorological station (Rovinj and Abrami). From the collected climatic data starting with January 1st we calculated mean degree-day accumulation (above 10°C) according to the methodology described by Kumral et al. [40].

Statistical software ARM 7 (Gylling Data Management, Revision 7.2.2, September 12th 2005) was used to calculate

correlation coefficients and to conduct regression analysis between the following variables:

(i). Mean degree-day accumulation (independent variable) versus cumulative capture of flies (dependent variable);
(ii). Cumulative capture of flies (independent variable) versus average percentage of total and active infestation (dependent variable);
(iii). Mean degree-day accumulation (independent variable) versus average percentage of total and active infestation of fruits (dependent variable);

The correlation coefficients were established, regression lines were described, and the coefficient of determination was calculated.

Based on calculated regression equation the expected total and active fruit infestations for early (October 16th) and for late harvesting (November 5th) were calculated. For the prediction of the changes in the oil quality parameters (total phenols, free fatty acids mass ratio, and peroxide value) linear regression slopes for particular olive cultivar and the same harvesting dates obtained by Koprivnjak et al. [13] were used.

3 Results

The mean degree-day accumulation and rainfall for both localities (Fig. 1) shows that there are differences in climatic conditions.

As was expected, a significant ($p = 0.0001$) positive correlation between DD accumulations and cumulative capture of flies was shown for both trap types and for both localities (Fig. 2, Table 1). Regression analysis of the DD accumulation (x) versus cumulative olive fruit fly capture (y) on YST + Ph and on McPhail traps (Fig. 2, Table 1) showed that the regression curves are exponential. Regression analysis of the cumulative olive fruit fly capture (x) on YST + Ph and on McPhail traps versus total and active infestation (Figs. 3 and 4, Table 2) showed that the regression curves are linear and correlations (measured by Pearson's coefficient of correlations) between those variables are very strong to full according to Roemer and Orphal [41]. All established correlations are significant ($p = 0.0001$–0.0186). Probability in some cases was influenced by the limited number of pairs involved in the analysis. The amount of variability measured by coefficient of determination (r^2) was higher if the total infestation was measured.

We expected that higher fly population pressure at locality Rovinj will result in higher fruit infestation of *Buža* cultivar

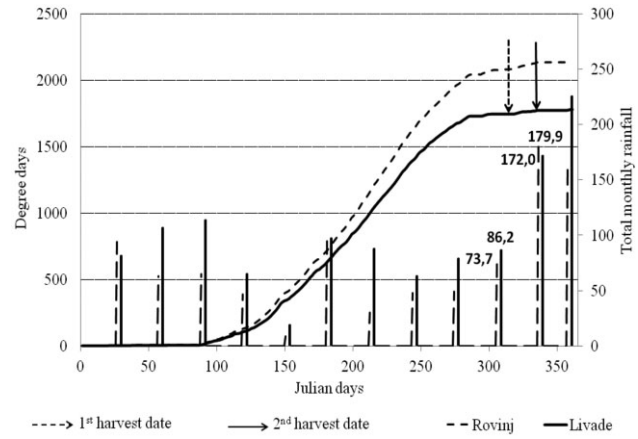

Figure 1. The mean degree-day accumulation (above 10 °C) and total monthly amount of rainfall at two experimental localities (Rovinj, Livade) in 2009.

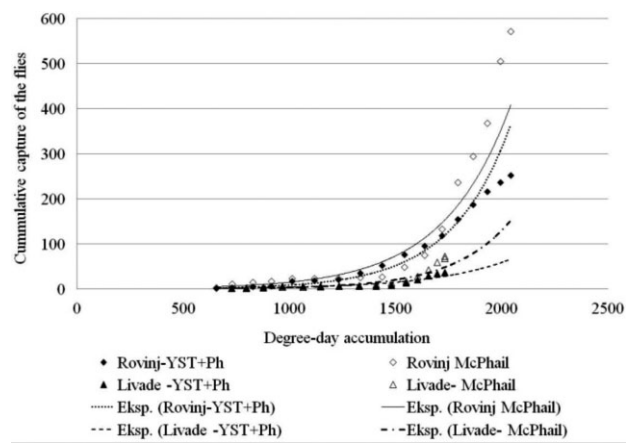

Figure 2. Regression analysis of degree-day accumulation (x) versus cumulative capture of the olive fruit fly on yellow sticky traps baited with pheromone (YST + Ph) and on McPhail trap (y) at two localities: Rovinj and Livade.

Table 1. Correlation coefficients, coefficients of determination and regression equations for cumulative capture of olive fruit flies (y) on yellow sticky traps (YST + Ph) and on McPhail traps on degree–day accumulations (x) at two localities, Rovinj and Livade in 2009

Locality and cultivar	Trap type	n	Correlation coefficient r	Coefficient of determination r^2	Probability p	Regression equation
Rovinj buža	YST + Ph	17	0.9809	0.9621	0.0001	$y = 0.239e^{0.0036x}$
	McPHAIL	17	0.958	0.917	0.0001	$y = 0.6405e^{0.0032x}$
Livade *I. bjelica*	YST + Ph	16	0.928	0.8612	0.0001	$y = 0.2498e^{0.0027x}$
	McPHAIL	16	0.9712	0.9433	0.0002	$y = 0.0803e^{0.0037x}$

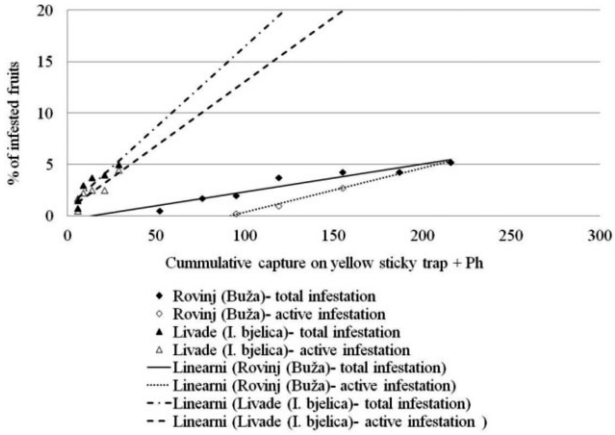

Figure 3. Regression analysis of the cumulative olive fruit fly capture on yellow sticky traps baited with pheromone (YST + Ph) (x) versus total and active fruit infestation of two olive cultivars (y) (*Buža* and *I. bjelica*) at two localities: Rovinj and Livade.

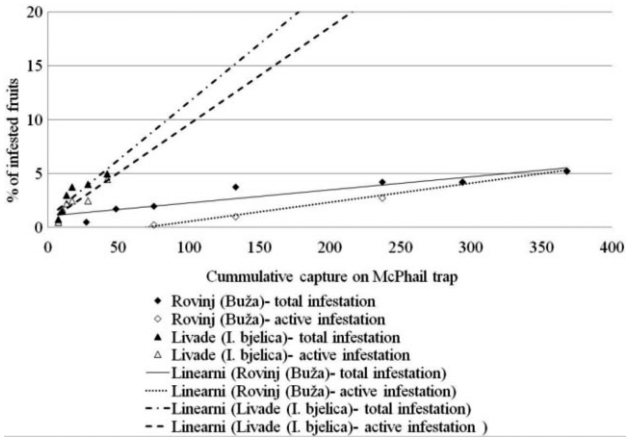

Figure 4. Regression analysis of the cumulative olive fruit fly capture on McPhail (x) versus total and active fruit infestation of two olive cultivars (y) (*Buža* and *I. bjelica*) at two localities: Rovinj and Livade.

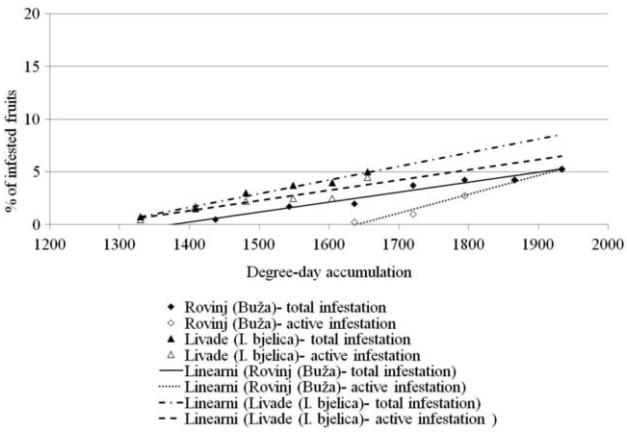

Figure 5. Regression analysis of degree-day accumulation (x) versus total and active fruit infestation of two olive cultivars (y) (*Buža* and *I. bjelica*) at two localities: Rovinj and Livade.

comparing to *I. bjelica*. That did not happen. At both localities total infestation density has reached up to 5.25% (Figs. 3 and 4).

Regression coefficients established for both total and active fruit infestation, of cultivar *I. bjelica* (y) on cumulative capture on McPhail traps (x) are approximately ten fold higher than for cultivar *Buža* (Table 2).

Full positive correlations were established between degree-day accumulations (independent variable) and total and active fruit infestations on both cultivars (Fig. 5). All established correlations are significant ($p = 0.0001$–0.0106). Probability in some cases also was influenced by limited number of pairs involved in the analysis. The amount of variability measured by coefficient of determination (r^2) was very high and the differences between total and active infestations could not be seen. Regression lines are linear, and regression coefficients are similar for both cultivars (Table 3).

Based on degree day (DD) accumulation on both harvesting dates at both localities, and based on calculated regression coefficients, we estimated active infestation for each harvesting date and for each olive cultivar. For the

Table 2. Correlation coefficients, coefficients of determination and regression coefficients for total and active fruit infestation (y) on cumulative capture of olive fruit flies (x) on yellow sticky traps (YST + Ph) and on McPhail traps on two olive cultivars (*Buža* and *I. bjelica*) at two localities (Rovinj and Livade)

Trap type	Locality and cultivar	Infestation	N	Correlation coefficient r	Coefficient of determination r^2	Probability p	Regression coefficient b
YST + Ph	*Rovinj buža*	Total	7	0.9541	0.9103	0.0008	0.0271
		Active	5	0.9979	0.9958	0.0001	0.0429
	Livade *I. bjelica*	Total	6	0.9038	0.8169	0.0134	0.157
		Active	6	0.8890	0.7903	0.0178	0.1251
McPhail	*Rovinj buža*	Total	7	0.9327	0.8699	0.0022	0.012
		Active	5	0.9954	0.9909	0.0004	0.0177
	Livade *I. bjelica*	Total	6	0.8864	0.7857	0.0186	0.1076
		Active	6	0.9162	0.8394	0.0102	0.0902

Table 3. Correlation coefficients, coefficients of determination and regression coefficients for total and active fruit infestation (*y*) on yellow sticky traps (YST + Ph) and on McPhail traps on degree-day accumulation (*x*) of two olive cultivars (*Buža* and *I. bjelica*) at two localities (Rovinj and Livade)

Locality and cultivar	Infestation	*n*	Correlation coefficient r	Coefficient of determination r^2	Probability *p*	Regression coefficient *b*
Rovinj buža	Total	7	0.9789	0.9583	0.0001	0.0094
	Active	5	0.9908	0.9817	0.0011	0.0179
Livade *I. bjelica*	Total	6	0.9890	0.9781	0.0002	0.013
	Active	6	0.9146	0.8366	0.0106	0.0097

cultivar *Buža* the estimated active fruit infestation on October 16th (the first harvesting date) is 7.196% and on November 5th (the 2nd harvesting date) is 7.87%. The last observed fruit infestation, at the end of September, was similar between cultivars. At locality Rovinj the DD accumulation was increasing faster and therefore the estimated active infestation of cultivar *Buža* was higher than those estimated for cultivar *I. bjelica*. The estimated active fruit infestation of cultivar *I. bjelica* on October 16th is 5.24% and on November 5th is 5.39%.

The estimated active fruit infestation and the data about the content of total phenols, free fatty acids (FFA) and peroxide value of healthy fruits of cultivars *I. bjelica* and *Buža*, together with the regression coefficients for each variable established by Koprivnjak et al., were used to predict changes in the total phenol contents (Table 4), FFA contents

Table 4. Estimated changes in the content of total phenols in fruits of two olive cultivars infested with olive fruit fly as it was estimated for October 16th and November 5th

	Buža		*I. bjelica*	
Parameter	October 16	November 5	October 16	November 5
y-total phenols content in healthy fruits[a)]	209	254	663	488
b-regression coefficient[a)]	−0.8966	−1.502	−1.394	−0.7786
x-active fruit infestation[b)]	7.196	7.87	5.24	5.39
$\hat{y}$-estimated total phenols content in fruit infested at *x*	202.55	242.18	655.7	483.8
Difference $\hat{y}$–*y*	−6.45	−11.82	−7.3	−4.2
Difference in % $= \frac{\hat{y}-y}{y} \times 100$	−3.09	−4.65	−1.1	−0.86

[a)]The data were obtained from Koprivnjak et al. [13].
[b)]Fruit infestation was estimated based on degree-day accumulation on two harvesting dates at each locality and based on regression coefficients shown in Table 3.

Table 5. Estimated changes in the free fatty acids mass ratio in fruits of two olive cultivars infested with olive fruit fly as it was estimated for October 16th and November 5th

	Buža		*I. bjelica*	
Parameter	October 16	November 5	October 16	November 5
y-free fatty acids mass ratio in healthy fruits[a)]	0.09	0.12	0.24	0.22
b-regression coefficient[a)]	0.001	0.0008	0.0019	0.0016
x-active fruit infestation[b)]	7.196	7.87	5.24	5.39
$\hat{y}$-estimated free fatty acids mass ratio in fruit infested at *x*	0.097	0.126	0.25	0.228
Difference $\hat{y}$–*y*	0.007	0.006	0.01	0.008
Difference in % $= \frac{\hat{y}-y}{y} \times 100$	+7.78	+5.0	+4.2	+3.6

[a)]The data were obtained from Koprivnjak et al. [13].
[b)]Fruit infestation was estimated based on degree-day accumulation on two harvesting dates at each locality and based on regression coefficients shown in Table 3.

Table 6. Estimated changes of peroxide value in fruits of two olive cultivars infested with olive fruit fly as it was estimated for October 16th and November 5th

	Buža		*I. bjelica*	
Parameter	October 16	November 5	October 16	November 5
y-peroxide value in healthy fruits[a)]	2.1	1.9	0.8	1.8
b-regression coefficient[a)]	0.0587	0.0467	0.0187	0.012
x-active fruit infestation[b)]	7.196	7.87	5.24	5.39
$\hat{y}$-estimated peroxide value in fruit infested at x	2.52	2.27	0.898	1.865
Difference $\hat{y}$–y	0.42	0.37	0.098	0.065
Difference in % $= \frac{\hat{y}-y}{y} \times 100$	+20	+19.50	+12.25	+3.6

[a)]The data were obtained from Koprivnjak et al. [13]
[b)]Fruit infestation was estimated based on degree-day accumulation on two harvesting dates at each locality and based on regression coefficients shown in Table 3.

(Table 5), and peroxide values (Table 6) under experimental condition.

4 Discussion

On the 1st harvesting day (October 16th, the DD accumulation at locality Rovinj reached 2041.9°C which was 310.7°C higher comparing to the locality Livade. On the 2nd harvesting date (November 5th) the DD accumulation at locality Rovinj reached 2079.5°C and was 333.2°C higher comparing to the locality Livade (meteorological station Abrami). Significant difference was determined in the total annual rainfall (919 mm for Rovinj vs. 1196 mm for Livade), while no significant difference was determined in the rainfall between localities in the harvest period, i.e., on both harvesting date (Fig. 1).

The olive fruit fly population level was higher at locality Rovinj than at locality Livade. The differences in population level are probably influenced by the differences in the total degree-day accumulations, which are on the other hand influenced by climatic conditions and by characteristics of the olive production areas [4, 42]. Furthermore, locality Rovinj is very close to an extensive olive orchard in which olives are not treated against olive fruit fly and the olive harvest is often too late, or olives are even left on the tree. That might contribute to a high population of flies at locality Rovinj.

McPhail traps showed to be more attractive to olive flies than yellow sticky traps baited with pheromone at both localities. Generally, the total capture on McPhail traps was double comparing to fly capture on YST + Ph traps at both localities (Fig. 2). Some authors [43, 44] give an explanation in which McPhail trap showed a better effect in a warm and dry period. In spite of the differences in population level, and the differences in the total capture on various trap types, at both localities and for both trap types the correlation coefficients (Table 1) were high and could be described as full positive correlation according to Roemer and Orphal [41]. At locality Rovinj the coefficient of determination (r^2) was high, 0.9621 for yellow sticky trap and 0.917 for McPhail, respectively. At locality Livade the coefficient of determination (r^2) was 0.8612 for yellow sticky trap and 0.9433 for McPhail. Regression curves at both localities and for both trap types have similar tendencies and are exponential. Exponential population growth at the end of the season impacts the increase in fruit damage.

Higher fly population pressure at locality Rovinj comparing to the locality Livade did not result in higher fruit infestation of *Buža* cultivar comparing to *I. bjelica*. The total infestations of cultivar *Buža* and cultivar *I. bjelica* were 5.25 and 5.0%, respectively (Figs. 3 and 4). The differences in fruit infestation of different cultivars are often explained by different susceptibility of cultivars to olive fly attack. In our investigation, both cultivars are proved to be susceptible to olive fly attack [35]. *I. bjelica* is characterized by a lower flesh/stone mass ratio (6.87), oval fruit shape and late ripening, while *Buža* has spherical fruits of somewhat higher flesh/stone mass ratio (8.24) and earlier ripening [33, 34]. Moreover, *I. bjelica* has significantly lower water content than Buža [13]. All these characteristics together make *I. bjelica* fruits a less favorable environment for larvae growth. Because of late maturity and other fruit characteristics *Buža* is expected to be more sensitive to larval attack. But this did not happen. Reasons could be found in specific climatic conditions prevailed in investigated olive orchards. The olive orchard in Rovinj is situated next to the coast, having high temperatures, and low relative humidity what is very important for egg hatching and larval development. During the summer period, the eggs behavior is characterized by a remarkable increase of mortality because of high temperature and this makes the eggs most susceptible stage to the high summer temperature [37]. High temperatures and low humidity prevent female maturation in summer months [5]. Explained conditions are probably the main reason why the fruit infestation of

cultivar *Buža* at locality Rovinj was not as high as it might be expected based on the fly population and fruit characteristics. More favorable climatic conditions at locality Livade contributed to the finding that regression coefficients established for both total and active fruit infestation, of cultivar *I. bjelica* on cumulative capture on McPhail traps (x) are approximately ten fold higher than for cultivar *Buža*. Therefore, the increase in fly capture (by using McPhail traps) for one specimen, would result with an increase of *I. bjelica* fruit infestation for 0.1%. The same increase in fly capture on cultivar *Buža* would result with an increase of approximately 0.01% of infested fruits (Table 2).

The fruit infestation was observed at locality Rovinj, at the time when the DD accumulation reached 1450 and 1950°C, and at locality Livade, at the time when the DD accumulation reached 1320 and 1650°C (Fig. 5). The increase of DD accumulation for 1°C (within the mentioned intervals) would result (Table 3) with an increase in total fruit infestation between 0.0094 and 0.013%. The same increase in degree-day accumulation would result with an increase in active fruit infestation between 0.0097 and 0.0179%. This finding confirms that earlier harvesting would prevent olive fruit fly damage in fruits [2, 5, 18, 27–29].

As it was established by Koprivnjak et al. [13] two investigated cultivars highly differ in the content of total phenols. Phenols are very important as main antioxidants and have a positive effect on oxidative stability and sensory properties because they give a bitter, pungent, and astringent taste in the olive oil [45]. The amount of phenolic compounds in olive oil are variable, depending on several factors such as cultivar, degree of maturation and the infestation by the olive fruit fly [46]. Differences in total phenol amount were established between several other cultivars [16, 47]. *I. bjelica* has two to threefold higher amounts of total phenols comparing to *Buža*. But, the lower predicted fruit infestation would result in the decrease of total phenols for 1.1% at earlier and 0.86% for late harvesting dates. The estimated change in total phenols (Table 4) is lower than those estimated for cultivar *Buža* (3.09 at the first and 4.65 at the second harvesting date, respectively). It is important to see that for cultivar *Buža*, which is already characterized with lower amount of total phenols, the difference in the total amount of phenols lost between first and second harvesting date was over 1.5% of total amount of phenols. The main reduction in total phenols in cultivar *I. bjelica* occurred if the fruits were harvested too late, the total amount at second harvesting date decreased for 30%. Therefore, in *I. bjelica* by earlier harvesting the total amount of phenols will be kept at high level because of the characteristics of cultivar. Fruit damage caused by olive fly larvae will influence only the low decrease in total phenols amount. This corresponds to the finding of Koprivnjak et al. [13] who stated that the fruit properties of *I. bjelica* are not favorable for larval development and the lower volume of mesocarp tissue damage in infested fruits is a reason for less pronounced phenols degradation.

Free fatty acids (FFA) mass ratio is one of the indicators of quality changes in olive fruits. There are differences between cultivars in FFA mass ratio in healthy fruits (Table 5) regardless the harvesting date [13]. *I. bjelica* has almost double FFA mass ratio comparing to *Buža* at both harvesting dates. The increase in FFA mass ratio in cultivar *Buža* with predicted fruit infestation would be 7.78% for early and 5% for late harvesting date. The increase in FFA mass ratio in cultivar *I. bjelica* with predicted fruit infestation would be 4.2% for early and 3.6% for late harvesting date. Nevertheless, FFA values for both cultivars, even at 100% of infestation level, were much lower than maximum limit for extra virgin (EV) category that is 0.8% [48]. This fact emphasises the importance of short storage time for olive fly infested fruits, since all samples in this experiment were processed within 24 h after harvesting. Results reported by Tamendjari et al. [18], Kyriakidis and Dourou [9], Delrio et al. [49], and Pereira et al. [47] confirm a limited increase of FFA in oils obtained from 100% infested fruits regarding corresponding samples obtained from healthy fruits. However, other researchers [7, 16] found that FFA ratio could be a discriminatory factor regarding EV category at 75–100% of infestation levels. Cited articles, however, do not explicitly mention the time passed from fruits harvesting to processing.

Peroxide value is the main indicator of oxidative degradation of olives. Two investigated cultivars differ at some extent in peroxide value. The difference is not as large as it was established for the other parameters. *Buža* has higher peroxide values at both harvesting dates comparing to *I. bjelica* at earlier harvesting date, while *I. bjelica* at late harvesting date had similar peroxide value as *Buža*. Based on our results (estimated infestation level) and parameters established by Koprivnjak et al. [13] we could predict (Table 6) the increase in peroxide value in the cultivar *Buža* of 20 and 19.5% for early and late harvesting date, respectively. The increase in peroxide value in the cultivar *I. bjelica* was lower, 12.25% for early and 3.6% for late harvesting date, respectively. The higher increase of peroxide value in *Buža* is the result of higher predicted infestation as well as higher regression coefficient. Differences among cultivars regarding the dynamics of oxidative oil degradation, have been also reported by other authors who based their experiment on the linearly increased infestation degree. Three Algerian cultivars studied by Tamendjari et al. [16] were rather similar in the hydrophilic phenols content of oil (from 176 to 290 mg/kg) and unsaturated/ saturated fatty acid ratio (from 5.3 to 6.3). In their study, the cultivar with the highest average fruit size and maturity level appeared the most sensitive, despite a more favorable unsaturated/saturated fatty acid ratio and hydrophilic phenols content. Research of Pereira et al. [47], however, did not include differences in the maturity level of three Portuguese cultivars and in the content of hydrophilic phenols, which are the main antioxidants in olive fruit. Different susceptibility of *I. bjelica* and *Buža* to oxidative degradation of oil contained in fruits attacked by larvae could

be related to the combination of several factors have been reported by Koprivnjak et al. [13]. A much higher content of hydrophilic phenols (on average 575 vs. 230 mg/kg), lower levels of linoleic acid (on average 8.0 vs. 12.5%), absence of ripening induced by olive fly attack and observed lower volume of mesocarp tissue damage, could explain remarkable oxidative stability of *I. bjelica*.

We established a strong positive correlation between DD accumulation and cumulative capture of flies on both types of traps. The population growth is exponential and very high at the end of the season, when olive fruits are ripening and show the highest level of receptivity. This would result with a linear increase in the total and active fruit infestations. The same olive fly population level would not result in the same infestation level which could be influenced by cultivar characteristics and by differences in climatic conditions.

Results discussed lead us to the conclusion that *I. bjelica* is less sensitive to decrease in total phenols amount, to increase in free fatty acids mass ratio and to increase in peroxide values comparing to *Buža*. Also the differences in investigated parameters between earlier and late harvesting dates in *I. bjelica* are lower due to lower infestation predicted for both harvesting dates and due to lower sensitivity to the changes in quality parameters. Therefore, early harvesting date as a model for preventing fruit damage as well as a model for preventing negative change in oil quality parameters is a valid tool. But, the effectiveness of this model could also depend on the characteristics of olive cultivar. Cultivars more sensitive to oxidative oil degradation (e.g., *Buža*) should be harvested earlier than those which are less sensitive or those with higher content of total phenols (e.g., *I. bjelica*).

5 Conclusions

We established a strong positive correlation between DD accumulation and cumulative capture of flies on both types of traps. The population growth is exponential and very high at the end of the season, when olive fruits are ripening and show the highest level of receptivity. This would result with a linear increase in the total and active fruit infestations. The same olive fly population level would not result in the same infestation level which could be influenced by cultivar characteristics and by differences in climatic conditions.

Results discussed lead us to the conclusion that *I. bjelica* is less sensitive to decrease in total phenols amount, to increase in FFA mass ratio and to increase in peroxide values comparing to *Buža*. Also the differences in investigated parameters between earlier and late harvesting dates in *I. bjelica* are lower due to lower infestation predicted for both harvesting dates and due to lower sensitivity to the changes in quality parameters. Therefore, early harvesting date as a model for preventing fruit damage as well as a model for preventing negative change in oil quality parameters is a valid tool. But, the effectiveness of this model could also depend on the characteristics of olive cultivar. Cultivars more sensitive to oxidative oil degradation (e.g., *Buža*) should be harvested earlier than those which are less sensitive or those with higher content of total phenols (e.g., *I. bjelica*).

The authors have declared no conflict of interest.

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