AGRICULTURAL BIOLOGY,
2020, V. 55, № 1, pp. 174-183
(SEL'SKOKHOZYAISTVENNAYA BIOLOGIYA)

ISSN 2412-0324 (English ed. Online)
ISSN 0131-6397 (Russian ed. Print)
ISSN 2313-4836 (Russian ed. Online)

Agricultural entomology, phytopathology

UDC 632.772:574.3(470.31)

doi: 10.15389/agrobiology.2020.1.174eng
doi: 10.15389/agrobiology.2020.1.174rus

BIOECOLOGICAL FEATURES OF CHERRY FLY *Rhagoletis cerasi* (L. 1758) (*Diptera*: *Tephritidae*) DEVELOPMENT IN THE CENTRAL NON-CHERNOZEM ZONE OF RUSSIA

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Received July 13, 2019

Abstract

Cherry fruit fly (*Rhagoletis cerasi* (L. 1758) (*Diptera*: *Tephritidae*)) in Central non-Chernozem zone of Russia appeared in the late 1990th—early 2000th, which is associated with global warming and the significant expansion in the acreage of forage plants in this region. Due to ecological plasticity the fly has quickly adapted to local conditions of habitat, and annually flies in a large number. This paper is the first to investigate dates of the flight start, dynamics and duration depending on weather conditions, the periods of egg laying, hatching and feeding of larvae, terms of cocoon formation in soil, and also the peculiarities of the pest diapause under the conditions of Central non-Chernozem Russia. Damage of fruits in cherry varieties of different time of ripening was also assessed. Based on these data, effective methods for monitoring the phytophage are proposed. The studies were carried out in 2016-2018 in the cherry plantations of the All-Russian Horticultural Institute for Breeding, Agrotechnology and Nursery (ARHIBAN, Moscow Province, Leninskii District, 55.47° n.l., 37.7° e.l., 124 m above sea level) on cherry (*Prunus cerasus* L.) varieties of early (Sania, Bagryanaya), middle (Molodezhnaya, Volochaevka) and late (Malinovka, Apukhtinskaya) ripening periods. To the end, the research is targeted to improve monitoring methods, increase the efficiency and environmental safety of protective measures. The harsh conditions of the northern horticultural zone had a significant impact on the bioecology of the northern phytophage population. Depending on the weather conditions, the beginning and duration of flying, egg laying, hatching of larvae, and pupation vary greatly from year to year. The beginning of flies in different years was observed when the sum of effective temperatures (SET) above 10 °C from 191.9 °C to 268.6 °C, with the difference in dates from 3 to 33 days; oviposition occurred at 227.4 °C to 285.1 °C, with the difference in dates to 27 days; hatching of larvae occurred at 290.3 °C to 347.1 °C, with the difference in dates from 2 to 24 days; the pupation occurred at 481.4 °C to 559.9 °C, with the difference in dates from 5 to 22 days. The feeding period of the larvae ranged from 18 to 26 days, and the imago flying period from 40 to 69 days. In the conditions if Central non-Chernozem Russia, both one-year and two-year diapauses *R. cerasi* are possible. In keeping larvae in special cages (under trees in the garden), after the first winter diapause, only 42.0 % of the overwintered individuals turned into adults. After the second winter diapause, those were 4.8 % of the initial number of larvae gone on diapause. In the third year, no flies were recorded. In two years, only 46.8 % of the individuals who went into diapause turned into adults, the rest died for various reasons. Also, the damage of cherry fruits varied from 7 % to 21 % for the early cultivars, from 38 % to 57 % for the middle-ripening cultivars, and from 61 % to 75 % for lthe ate-season maturing cultivars. Determination of *R. cerasi* phenophases based on calendar dates and phenophases of the host plant gives contradictory results in different years. Bilateral yellow glue traps combined with SET estimates and visual control of fruit ripening can improve *R. cerasi* monitoring to enable effective protective measures.

Keywords: insect, *Diptera*, *Rhagoletis cerasi* L., pest, bio-ecology, diapause, sum of effective temperatures

The European cherry fruit fly *Rhagoletis cerasi* L. (1758) (*Diptera*: *Tephritidae*) is the most economically significant phytophage of cherries and cherries

in Europe [1-3] and Asia [4], including Russia [5-7]. In recent years, its invasion into North America has been noted [7, 8], where this phytophage causes significant damage along with other species of the genus *Rhagoletis* (*R. cingulata*, *R. indifferens*, and *R. fausta*) [9-11]. Studies conducted in different countries and geographical areas revealed several races of *R. cerasi* [12-14], however, the southern and northern races are more often mentioned [15-17]. Females of the northern race, when crossed with males of the southern, are barren, females of the southern race, when mating with males of the north, give offspring [16-18]. A number of scientific papers emphasize that this phenomenon is due to the presence of an intracellular bacterial infection of Wolbachia [19-21], maternally inherited and spreading in the host populations by the mechanism of cytoplasmic incompatibility (CI), which leads to embryonic mortality during mating infected males with uninfected females or females with another strain of Wolbachia [20-22].

Possible differences in the bioecology of the southern and northern populations of *R. cerasi* are of particular importance. In recent decades, due to global warming, the advancement of cherry plantings in the northern regions, creation of new frost-resistant varieties and an increase in cultivation areas, the area of the phytophage in the northern gardening has significantly expanded. Cherry fly is an oligophage. In addition to *Prunus* sp. (*P. cerasus*, *P. avium*, *P. serotina*, *P. mahaleb*), *R. cerasi* damages *Lonicera* sp. (*L. xylosteum*, *L. tatarica*) [23, 24]. The bioecology of *R. cerasi* is closely depends on agroecological conditions, including air and soil temperatures at different periods, precipitation, as well as the phenology of the host plants, i.e. cultivar peculiarities and fruit quality, since the survival of the phytophage depends on synchronization, due to pupal diapause, of the appearance of adults with the presence of fruits [25, 26].

In the late 1990s and early 2000s, individuals of a cherry fly were quite rare found in the Central Non-Chernozem Zone (CNZ). Currently, in this region there is an annual massive damage by this pest. On untreated plantations, the damage to fruits is constantly increasing. Now it reaches up to 70-75%, and, according to reports, in the absence of protective measures, fruit damage can reach 100% [27, 28).

In the present work, we first described the phenology and high harmfulness of *R. cerasi* in the Central Non-Chernozem Zone. The start dates of the flight, the dynamics and the duration of the fly's flight, depending on weather conditions, egg laying, hatching and feeding of the larvae, their departure to the soil for coconing, and also the diapause of the pest in the CNZ conditions are determined. Based on the assessment of damage to cherry fruits, effective methods for monitoring the phytophage are proposed.

The aim of the work was to study the bioecological features and development of cherry flies on cherry varieties that ripen at different times in the Central Non-Chernozem Zone of Russia to improve monitoring and measures for more effective and environmentally friendly plant protection against the pest.

Materials and methods. The investigations were carried out in 2016-2018 in the cherry plantations of the All-Russian Institute of Horticulture and Nursery (ARHIBAN, Moscow Province, Leninsky District, 55.47° N, 37.7° E, 124 m above sea level) on early (Sania, Bagryanaya), mid-season (Molodezhnaya, Volochaevka) and late (Malinovka, Apukhtinskaya) cherry varieties in the lab plot and in the demonstration garden.

To detect the beginning and dynamics of *R. cerasi* flight, 5 days after the end of the early ripening cherry flowering periods, yellow double-sided adhesive traps were hung at 1.7 m height on trees from the southern and southeastern

sides on the outer projection of a tree crown in 10 sites (one tree per site), trap dimensions 20×10 cm. Before the first flying flies and after July 25 (until the end of the flight), traps were inspected daily, the rest of the time 2-3 times a weekю. Five days after the detection of flies in the traps, 300 fruits were picked daily (30 from each test site) and examined (a binocular microscope MBS-10, LZOS OJSC, Russia), and in 10 females were daily dissected to determine if off-laying eggs. Two days after the detection of eggs, the fruits were selected and examined daily in search of hatching larvae.

Two weeks after the detection of hatching larvae, daily, 1000 ripening or ripened fruits (100 per site), without picking from the trees, were examined with a magnifying glass for the presence of outlet holes of larvae. When revealing holes, the fruits were torn off, cut into two parts and examined under the binocular to establish damage typical for *R. cerasi*.

To determine the damage to different varieties, saline solution was used [3]. Before mass harvesting, 100 fruits were randomly collected from trees of each cultivar, the seeds were separated from the pulp, and the fruits were cut into several smaller parts and placed in saturated saline (350 g salt/l water). After 10 min, the emerged larvae were counted.

To establish the diapause period, during full ripeness, damaged fruits were collected three times with a 2 day interval, placed on dry sand layer 2 cm thick [29] and left in a room out of direct sunlight. After 1 week, the sand was sieved, 500 puparia were collected, placed in cages, 50 individuals per each, at a 5 cm depth. The cages were 20×30 cm boxes, lined on the inside with a plastic film filled with a mixture of soil from the garden, peat and sand (1:1:1, 10 cm thick layer). Cages were buried in the garden to the edges of the box at ground level on the south side of the trees. Cages were covered from three sides and from above (roof height 30 cm, rectangular shape) with a fine mesh net (meshes about 0.8 mm), and from the northern side a tight-fitting window was made of polyethylene. During the growing season, weeds growing in cages were cut off with secateurs through a window and removed (the plants were not torn out so as not to disturb pupae). Shortly before the flight period of *R. cerasi*, yellow glue traps were installed inside the cage through a window. Traps with flies adhering to them were removed every week after counting.

Mean sample value (M) and the standard deviation of the mean ($\pm\sigma$) were calculated from the dates of observations for each site, the significance of the differences was evaluated by the Fisher F-test. Statistical processing of tabular data was performed according to Dospekhov [30] using the Microsoft Excel software.

Results. Weather during the years of research (according to the weather station of Domodedovo Airport) are presented in Table 1.

Despite the significant influence of sharply changing weather conditions in the CNZ, *R. cerasi* individuals, due to environmental plasticity and adaptive capabilities, were able to synchronize their development with fruit formation and ripening of the host plant. The damage to varieties of different ripening periods varied over the years (Table 2), but ensured the survival of the *R. cerasi* population.

On the one hand, this was due to the possibility of prolonged diapause of the pupal stage in the soil (up to 10-11 months, with about 6 months at temperatures below 5-7 °C), and on the other, due to the ability of larger pupae to pause more than 1 years [29, 31, 32], as well as with an unequal response to the effects of prolonged low temperatures in different pupae (in some this process ends at the end of December, in others in March) [14]. According to the litera-

ture, in the post-diapause development of the pupa, stage II is reversible, i.e., a return is possible to stage I to remain in soil until the next season, which may be due to a response to environmental signals or to metabolic stimuli [33]. Soil composition may also affect the proportion of pupae diapausing for 1 year or more: in heavy clay soils, the percentage of additional diapausing pupae increases [34].

1. Air temperature and rainfall during observations of *Rhagoletis cerasi* L. development on cherry (*Prunus cerasus* L.) varieties (Domodedovo Airport weather station)

Parameter	Year	Month							
		III	IV	V	VI	VII	VIII	IX	X
Long-term average air temperature, °C		–1.4	5.8	13.2	17.0	19.2	17.0	11.3	5.1
Deviation from long-term average air temperature, °C	2016	+1.9	+2.3	+1.8	+1.2	+1.7	+2.5	–0.2	–1.1
	2017	+3.4	–0.5	–2.3	–2.5	–1.3	+1.8	+1.2	-0.5
	2018	+0.5	+1.4	+1.4	+0.3	+1.2	+2.3	+0.9	+0.6
Long-term average rainfall, mm		35	37	50	80	85	82	65	59
Deviation from long-term average rainfall, %	2016	114	92	126	76	144	204	91	90
	2017	126	214	168	175	124	83	43	115
	2018	83	108	142	87	108	54	89	66

In our experiments, out of 500 puparia that went to wintering in 2015, only 210 flies flew out the following year, which amounted to 42.0% of the original population. In 2017, 4.8% flew out, in 2018, that is, after the third season of diapause, no *R. cerasi* flies were found in cages. Over two seasons, 234 flies flew (46.8% of the puparia leaving for diapause in cages). This is a high percentage of flight compared to the natural conditions of diapause, where the percentage of flying adults varies greatly from year to year depending on environmental conditions and sometimes may not exceed 5-15% of the initial number of individuals leaving for wintering [35, 36].

2. Damage to cherry (*Prunus cerasus* L.) fruits caused by *Rhagoletis cerasi* L. fly during observation (Moscow Province, Leninsky District)

Variety	Ripening type	Damage, %			$M\pm\sigma$
		2016	2017	2018	
Sania	Early	17	8	15	13.3±4.7
Bagryanaya	early	21	7	12	13.3±7.1
Molodezhnaya	Mid-season	57	38	49	48.0±9.5
Volochaevka	Mid-season	53	41	43	45.7±6.4
Malinovka	Late	61	75	63	66.3±7.6
Apukhtinskaya	Late	64	73	68	68.3±4.5
$M\pm\sigma$		45.5±20.9	40.3±29.8	41.7±23.6	

Note. $F_{variety} > F_{01}$, $F_{year} < F_{05}$.

Depending on weather conditions, the beginning of the flight of flies fluctuated strongly over the years. As a rule, flies were found in traps a few days later than the actual departure date. The difference in dates ranged from 3 to 33 days (Table 3), and in terms of the sum of effective temperatures (SET) above 10 °C from 26.6 to 76.7 °C. At the same time, the choice of the threshold temperature for calculating the SET at a 10 °C level was more appropriate. In contrast to Southern and Western Europe, where winters are mild and spring temperatures rise evenly, winter is more severe in the central temperature zone, there are sharp jumps in air temperature in the spring. So, in 2016-2018, in March, the temperature ranged from –20 to +10 °C, in April — from –5 to +24 °C. A short-term increase in the average daily temperature above 7 °C could alternate with a sharp decrease (below 0 °C) for a long time, which did not contribute to the stable development of the pupa. Therefore, the calculation of SET above 5 or 7 °C, adopted in Southern, Western and Central Europe [1, 28, 37, 38], is less suitable in our zone and demonstrates a much larger fluctuation over the years (from 58.7

to 132.2 °C) in comparison to SET above 10 °C (from 26.6 to 76.7 °C) (Fig. 1). The calculation of SET above 10 °C for *R. cerasi* was carried out in other scientific studies conducted in Russia [14, 39].

3. Sums of effective temperatures (SET) **above 10 °C to start the *Rhagoletis cerasi* L. fly development on cherry plants during observation** (Moscow Province, Leninsky District)

Stage of development	2016		2017		2018	
	date	SET, °C	date	SET, °C	date	SET, °C
First flies in traps	06/03	191.9	07/06	268.6	06/06	218.5
Beginning of egg laying	06/14	227.4	07/11	285.1	06/14	280.8
Beginning of larvae hatching	06/20	290.3	07/14	310.2	06/22	347.1
Beginning of pupation	07/12	530.3	08/01	481.4	07/17	559.9

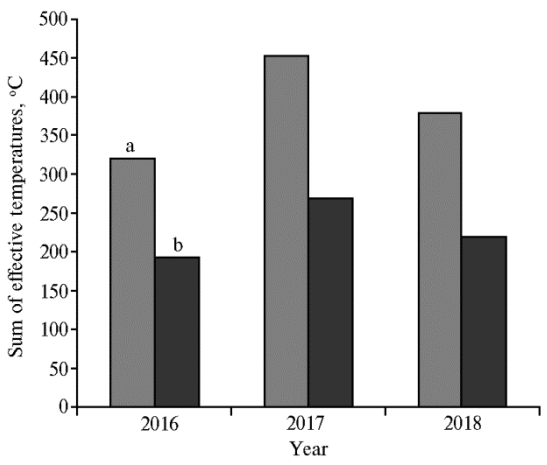

Fig. 1. Sums of the effective temperatures at appearance of *Rhagoletis cerasi* L. flies on the cherry (*Prunus cerasus* L.) at different thresholds during observation: a — above 7 °C, b — above 10 °C (Moscow Province, Leninsky District).

The period of additional feeding of flies before the laying of the first eggs (*R. cerasi* is a synovigenic species) took from 5 to 11 days. The difference in the SET accumulated by the beginning of the laying of eggs ranged from 4.3 to 57.7 °C, while the minimum difference in SET was between 2017 and 2018 and amounted to 27 days. The embryo development took from 3 to 8 days. The difference in the SET by the beginning of larvae hatching also varied significantly over the years, from 19.9 to 56.8 °C, the minimum value of this indicator was between 2016 and 2017 (24 days). The period of feeding of the first larvae leaving for pupation took from 18 to 26 days with a difference in SET to start the movement of larvae into the soil from 29.6 to 78.5 °C. The minimum SET was recorded in 2017 with the abnormally cold first half of the growing season.

The dynamics and intensity of the *R. cerasi* flight (Fig. 2) did not differ significantly in all 3 years of observation, although in 2016-2017 the number of flies increased evenly and, reaching a peak, also decreased evenly, and in 2018 there were three peaks of abundance, which was the result of a sharp fluctuation in air temperature. However, it should be emphasized that the maximum number of flies in all years of observations was noted in the middle of the flight period, which took from 8 to 14 days. The duration of the flight period of *R. cerasi* depended on weather conditions, food supply (including the duration of the fruit ripening period, thoroughness of harvesting) and ranged from 40 (2017) to 69 days (2018). In 2016, the flight lasted 55 days.

In the CNZ, the onset of *R. cerasi* release from winter diapause and the development of subsequent stages strongly fluctuated both in time and in SET (see Table 3). Since the microclimate of a particular location has a significant influence on the development of cherry flies, SET cannot guarantee the estimate of the exact time of the *R. cerasi* development individual phases. However, SET can be a good guideline in planning protective measures against the pest accounting changes in the fly activity as influenced by air temperature (at tempera-

tures below 15-16 °C, mating and eggs laying ceases, embryonic development lengthens) and rain intensity (heavy rain can lead to the death of adults) [4, 14, 39]. More reliable information on the flight start and dynamics can give, along with SET calculation, the use of yellow glue traps and visual observation of maturity and quality of fruits which also affect phytophage development. This fact was noted by other researchers [32, 40] and also confirmed by our data, indicating that on merry trees, the fly outbreaks and development are about 1 week ahead of those on cherries [7, 41, 42]. Note that more accurate timing of plant protection is especially important when using biologicals that have a significantly shorter action than chemicals [3].

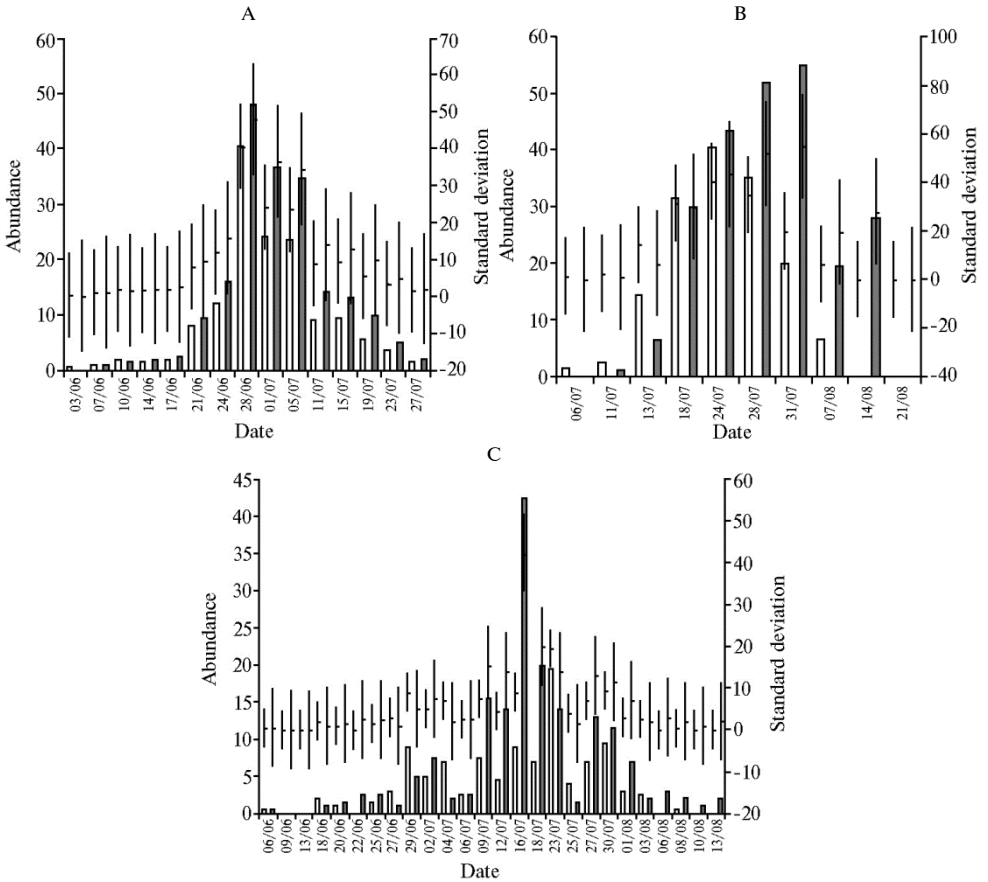

Fig. 2. Flight dynamics (abundance per trap on average) **of *Rhagoletis cerasi* L. fly on cherry (*Prunus cerasus* L.) plants in 2016** (A)**, 2017** (B)**, and 2018** (C) (light columns for the lab plot, dark columns for the demonstration garden) (Moscow Province, Leninsky District)**.**

In contrast to the southern regions, where early varieties, as a rule, go away from damage by a cherry fly, since the fruits ripen by the beginning of the mass egg laying by the phytophage [25, 39], in the CNZ the damage to these varieties, depending on the year conditions, reaches 7-21%. However, most of the larvae do not have time to finish feeding and are removed from the plantations together with the collected fruits. The highest damage is observed in varieties of late ripening (61-75%), but even in these varieties, as in mid-season varieties, some larvae do not have time to pupate before harvesting as the period when the flies exit diapause is uneven and quite extended. Despite the peak of flies in the garden occurs by the ripening fruits of late cherry variety (see Fig. 2), the flight, though much less intensive, continued even after the mass harvesting

was completed, within 2-5 days. It is known that the reproductive potential of females by this time sharply decreases, in the last days of flight they do not lay eggs [29], but improper harvesting allows larval to complete feeding significantly increases the number of wintering (diapausing) pests.

It should be noted that under the semi-artificial conditions that we created in our experiments, 53.2% puparia did not emerged as adults. This is significantly more than in lab growing with 5-25% death of pupae [33], but less than the indicators for natural habitats in other regions [35, 36].

Thus, in the climate conditions of the Central Non-Chernozem Zone (CNZ) of the Russian Federation, there is both a one-year and a two-year diapause of *Rhagoletis cerasi* L. The 89.7% flies emerged after a one-year diapause, 10.3% after a biennial diapause as per the total number of flies flown out. In the third year, no flies were detected in cages, which could be due to both bioecological features of their northern population and the influence of biotic (accumulation of predators, parasites, and pathogens in cages) and an abiotic stress factors. In the CNZ, *R. cerasi* damages cherry varieties of all ripening types, 7-21% fruits in early varieties, 38-57% in mid-season varieties, and 61-75% in late varieties. The emergence of adults after winter diapause fluctuates strongly both in dates (from 3 to 33 days) and in the sum of effective temperatures (SET from 191.9 to 268.6 °C). The tendency for other stages of pest development is the same, i.e. within 27 days (from 227.4 to 285.1 °C) to start laying eggs, from 2 to 24 days (from 290.3 to 347.1 °C) to start hatching of larvae, and from 5 to 20 days (from 481.4 to 559.9 °C) to start the larvae to pupate. The flight period of adults during our observation took from 40 to 69 days. A reliable method of monitoring the dynamics of *R. cerasi* flight is the use of yellow glue traps corrected to SET estimates and visual control of fruit quality and maturity.

REFERENCES

1. Kovanci O.B., Kovanci B. Reduced-risk management of *Rhagoletis cerasi* files (host race *Prunus*) in combination with a preliminary phenological model. *Journal of Insect Science*, 2006, 6(1): 34 (doi: 10.1673/031.006.3401).
2. Özdem A., Kılınçer N. The effectiveness of the trap types and lures used for mass trapping to control cherry fruit fly [*Rhagoletis cerasi* (L., 1758)] (*Diptera*: *Tephritidae*). *Munis Entomology and Zoology*, 2009, 4(2): 371-377.
3. Daniel C., Grunder J. Integrated management of European cherry fruit fly, *Rhagoletis cerasi* (L.): situation in Switzerland and Europe. *Insects*, 2012, 3(4): 956-988 (doi: 10.3390/insects3040956).
4. Mohamadzade N.S., Rasoulian G.R. A review of fruit files of the genus *Rhagoletis* (*Diptera*: *Tephritidae*) of Iran and bordering countries, with the key to species. *Vestnic Zoologii*, 2009, 43(1): 25-30 (doi: 10.2478/v10058-009-0003-0).
5. Vasil'eva L.A. *Materialy Mezhdunarodnoi nauchno-prakticheskoi konferentsii «Biologicheskaya zashchita rastenii — osnova stabilizatsii agroekosistem»* [Mat. Int. Conf. «Biological plant protection — the basis for sustainable agroecosystems»]. Krasnodar, 2010, tom 6: 381-387 (in Russ.).
6. Zeinalov A.S. *Zashchita i karantin rastenii*, 2013, 8: 39-40 (in Russ.).
7. Zeinalov A.S. *Osnovnye vrediteli i bolezni plodovykh kul'tur i sistemy meropriyatii po ogranicheniyu ikh vredonosnosti* [The main pests and diseases of fruit crops and the measures to limit their harmfulness]. Moscow, 2018 (in Russ.).
8. Dowell R.V., Penrose R.L. Distribution and phenology of *Rhagoletis fausta* (Osten Sacken 1877) and *Rhagoletis indifferens* Curran 1932 (Diptera: Tephritidae) in California. *The Pan-Pacific Entomolgist*, 2012, 88(2): 130-150 (doi: 10.3956/0031-0603-88.2.130).
9. Smith T.J. Western cherry fruit fly (*Rhagoletis indifferens* {Curran}) and its management in the pacific northwest United States of America. 2017. Available: http;//extension.wsu.edu/ chelandouglas/agriculture/treefruit/pestmanagement/cherry-fruitfly. Accessed: 10.01.2019.
10. Yee W.L. Efficacies of *Rhagoletis cerasi* (*Diptera*: *Tephritidae*) traps end ammonium lures for western cherry fruit fly. *Journal of Insect Science*, 2018, 18(3): 14; 1-8 (doi: 10.1093/jisesa/iey054).
11. Wakie T.T., Yee W.L., Neven L.G. Assessing the risk of establishment of *Rhagoletis cerasi* (*Diptera*: *Tephritidae*) in the United States and globally. *Journal of Economic Entomology*, 2018,

111(3): 1275-1284 (doi: 10.1093/jee/toy054).
12. Vasil'ev V.P., Livshchits I.Z. *Vrediteli plodovykh kul'tur* [Pests of fruit crops]. Moscow, 1984 (in Russ.).
13. Blümel S., Keck M., Nowotny N., Fiedler W., Russ K. Nachweis und Therapie von Rickettsia-like organisme (RLO′s) in den Ovarien der europäischen kirschfruchtfliege (*Rhagoletis cerasi* L.; *Trypetidae*): Ein Beitrag zur Frage der unidirektionalen Kreuzungssterilitat dieser Art. *Pflanzenschutzberichte*, 1991, 52: 41-47.
14. Moraiti C.A., Nakas Ch.T., Köppler K., Papadopoulos N.T. Geographical variation in adult life-history traits of the European cherry fruit fly *Rhagoletis cerasi* (*Diptera*: *Tephritidae*). *Biological Journal of the Linnean Society*, 2012, 107(1): 137-152 (doi: 10.1111/j.1095-8312.2012.01930.x).
15. Augustinos A.A., Asimakopoulou A.K., Moraiti C.A., Mavragani-Tsipidou P., Papadopoulos N.T., Bourtzis K. Microsatellite and *Wolbachia* analysis in *Rhagoletis cerasi* natural populations: population structuring and multiple infections. *Ecology and Evololution*, 2014, 4(10): 1943-1962 (doi: 10.1002/ece3.553).
16. Schuler H., Köppler K., Daxböck-Horvath S., Rasool B., Krumböck S., Schwarz D., Hoffmeister T.S., Schlick-Steiner B.C., Steiner F.M., Telschow A., Stauffer Ch., Arthofer W., Riegler M. The hitchhiker's guide to Europe: the infection dynamics of an ongoing *Wolbachia* invasion and mitochondrial selective sweep in *Rhagoletis cerasi*. *Molecular Ecolology*, 2016, 25(7): 1595-1609 (doi: 10.1111/mec.13571).
17. Bakovic V., Schebeck M., Telschow A., Stauffer C., Schuler H. Spatial spread of *Wolbachia* in *Rhagoletis cerasi* populations. *Biolology Letters*, 2018, 14(5): 20180161 (doi: 10.1098/rsbl.2018.0161).
18. Schebeck M., Feldkirchner L., Stauffer Ch., Schuler H. Dynamics of an ongoing *Wolbachia* spread in the European cherry fruit fly, *Rhagoletis cerasi* (*Diptera*: *Tephritidae*). *Insects*, 2019, 10(6): 172 (doi: 10.3390/insects10060172).
19. Schuler H., Kern P., Arthofer W., Vogt H., Fischer M., Stauffer C., Riegler M. *Wolbachia* in parasitoids attacking native European and introduced Eastern cherry fruit flies in Europe. *Environmental Entomology,* 2016, 45(6): 1424-1431 (doi: 10.1093/ee/nvw137).
20. Riegler M., Stauffer C. *Wolbachia* infections and superinfections in cytoplasmically incompatible populations of the European cherry fruit fly *Rhagoletis cerasi* (Diptera: Tephritidae). *Molecular Ecology*, 2002, 11(11): 2425-2434 (doi: 10.1046/j.1365-294X.2002.01614.x).
21. Kounatidis I., Papadopoulos N., Bourtzis K., Mavgarani-Tsipidou P. Genetic and cytogenetic analysis of the fruit fly *Rhagoletis cerasi* (*Diptera*: *Tephritidae*). *Genome*, 2008, 51(7): 479-491 (doi: 10.1139/G08-032).
22. Arthofer W., Riegler M., Schneider D., Krammer M., Miller W.J., Stauffer C. Hidden *Wolbachia* diversity in field populations of the European cherry fruit fly, *Rhagoletis cerasi* (*Diptera*: *Tephritidae*). *Molecular Ecology*, 2009, 18(18): 3816-3830 (doi: 10.1111/j.1365-294X.2009.04321.x).
23. White I.M., Elson-Harris M.M. *Fruit flies of economic significance: their identification and bionomics*. CAB International, Wallingford, Oxon, UK: 1992.
24. Schwarz D., McPheron B.A., Hartl G.B., Boller E.F., Hoffmeister T.S. A second case of genetic host races in *Rhagoletis*? A population genetic comparison of sympatric host populations in the European cherry fruit fly, *Rhagoletis cerasi*. *Entomologia Experimentalis et Applicata*, 2003, 108(1): 11-17 (doi: 10.1046/j.1570-7458.2003.00065.x).
25. Stamenkovic S., Garic R., Milenkovic S., Nikolic M., Stamenkovic T. Susceptibility of some sweet cherry cultivars to *Rhagoletis cerasi* L. (*Diptera*, *Tephritidae*). *Acta Horticulturae*, 1996, 410: 555-560 (doi: 10.17660/actahortic.1996.410.91).
26. Balázs K., Jenser G. Significance of the parasitoids and predators in IPM of sour-cherry. *IOBC/wprs Bulletin*, 2004, 27(5): 3-7.
27. Katsoyannos B. European cherry fruit fly, *Rhagoletis cerasi* (L.) (*Diptera*: *Tephritidae*). In: *Encyclopedia of entomology*. J.L. Capinera (ed.). Springer, Dordrecht, 2008 (doi: 10.1007/978-1-4020-6359-6_3687).
28. Nježić B., Pećanin D., Đurić G. Improvement of management of *Rhagoletis cerasi* in Bosnia and Herzegovina based on a phenological model. *Proceedings of the Latvian Academy of Sciences. Section B. Natural, Exact, and Applied Sciences*, 2017, 71(3): 229-232 (doi: 10.1515/prolas-2017-0038).
29. Moraiti C.A., Nakas C.T., Papadopoulos N.T. Prolonged pupal dormancy is associated with significant fitness cost for adults of *Rhagoletis cerasi* (*Diptera*: *Tephritidae*). *Journal of Insect Physiology*, 2012, 58(8): 1128-1135 (doi: 10.1016/j.jinsphys.2012.05.012).
30. Dospekhov B.A. *Metodika polevogo opyta* [Methods of field trials]. Moscow, 1985 (in Russ.).
31. Papanastasiou S.A., Nestel D., Diamantidis A.D., Nakas C.T., Papadopoulos N.T. Physiological and biological patterns of a highland and a coastal population of the European cherry fruit fly during diapause. *Journal of Insect Physiology*, 2011, 57(1): 83-93 (doi: 10.1016/j.jinsphys.2010.09.008).
32. Moraiti C.A., Nacas C.T., Papadopoulos N.T. Diapause termination of *Rhagoletis cerasi* pupae is regulated by local adaptation and phenotypic plasticity: escape in time through bet-hedging strategies. *Journal of Evolutionary Biology*, 2014, 27(1): 43-54 (doi: 10.1111/jeb.12273).

33. Papanastasiou S.A., Papadopoulos N.T. Description of *Rhagoletis cerasi* (*Diptera*: *Tephritidae*) pupal developmental stages: indications of prolonged diapause. *Journal of Insect Science*, 2014, 14(1): 156-160 (doi: 10.1093/jisesa/ieu018).
34. Hahn D.A., Denlinger D.L. Meeting the energetic demands of insect diapause: nutrient storage and utilization. *Journal of Insect Physiology*, 2007, 53(8): 760-773 (doi: 10.1016/j.jinsphys.2007.03.018).
35. Herz A., Köppler K., Vogt H. Kann der Einsatz entomopathogener nematoden zur nachhaltigen bekämpfung der kirschfruchtfliege beitragen? *Proceedings of the 9. Wissenschaftstagung Ökologischer Landbau*. S. Zikeli, W. Claupein, S. Dabbert, B. Kaufmann, T. Müller, A. Valle Zárate (eds.). Verlag Dr. Köster, Berlin, Germany, Universität Hohenheim, 2007: 277-280.
36. Daniel C. *Entomopathogenic fungi as a new strategy to control the European cherry fruit fly Rhagoletis cerasi Loew (Diptera: Tephritidae). PhD thesis*. Technische Universität München, Germany, 2009.
37. Baker C.R.B., Miller G.W. The effect of temperature on the post-diapause development on four geographical populations of the European cherry fruit fly (*Rhagoletis cerasi*). *Entomologia Experimental et Applicata*, 1978, 23(1): 1-13 (doi: 10.1111/j.1570-7458.1978.tb02725.x).
38. Jarošík V., Honěk A., Magarey R.D., Skuhrovec J. Developmental database for phenology models: related insect and mite species have similar thermal requirements. *Journal of Economic Entomology*, 2011, 104(6): 1870-1876 (doi: 10.1603/EC11247).
39. Vasil'eva L.A. *Biologo-ekologicheskoe obosnovanie elementov integrirovannoi zashchity chereshni i vishni ot vishnevoi mukhi Rhagoletis cerasi L. (Diptera: Trypetidae) v usloviyakh Krasnodarskogo kraya. Avtoreferat kandidatskoi dissertatsii* [Biological and ecological basis of integrated protection from cherry fly *Rhagoletis cerasi* L. (*Diptera*: *Trypetidae*) in the Krasnodar Territory. PhD Thesis]. Voronezh, 2009 (in Russ.).
40. Karlidag H., Ercisli S., Sengul M., Tosun M. Physico-chemical diversity in fruits of wild-growing sweet cherries (*Prunus avium* L.). *Biotechnology and Biotechnological Equipment*, 2009, 23(3): 1325-1329 (doi: 10.1080/13102818.2009.10817663).
41. Zeinalov A.S., Upadysheva G.Yu. V sbornike: *Selektsiya i sortorazvedenie sadovykh kul'tur* [In: Horticulture: selection and cultivation]. Orel, 2015, tom 2: 84-86 (in Russ.).
42. Zeinalov A.S. *Materialy Vserossiiskoi konferentsii s mezhdunarodnym uchastiem «Monitoring i biologicheskie metody kontrolya vreditelei i patogenov drevesnykh rastenii: ot teorii k praktike»* [Proc. All-Russian Conf. «Monitoring and biocontrol of pests and pathogens of woody plants: from theory to practice»]. Krasnoyarsk, 2016: 87-88 (in Russ.).