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THE BIO-ECOLOGY OF NORTHERN POPULATIONS OF THE PLUM MOTH *Grapholitha funebrana* Tr. (*Lepidoptera*: *Tortricidae*) IN THE CONTEXT OF CLIMATE CHANGE IN THE CENTRAL NECHERNOZEM ZONE OF RUSSIA

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Abstract

Climate change over the last decades and rising global temperatures, especially in the Northern latitudes, affect ecosystems, including agricultural sector. The crops naturally grown in southern and central Russia are now expanding to northern areas along with dangerous pests that are not characteristic of these areas. Plum moth *Grapholitha funebrana* Tr. causes over 80 % yield losses. At least 3-4 treatments are required during the growing season to ensure the profitability. Chemical and environmentally friendly methods (pheromone traps) are of practical use. Anyway, successful protection requires detailed biological and ecological characterization of the pest in a specific area. In the Central Non Chernozem Zone of Russia such studies have not yet been conducted. This paper is the first evidence of *G. funebrana* wide spread in the Central Non Chernozem Zone where the pest can produce two generations. The study was carried out in the fruit-bearing plum plantations (All-Russian Horticultural Institute for Breeding, Agrotechnology and Nursery, Moscow Region, Leninskii district) in 2015-2017. Summer dynamics of *G. funebrana* population was monitored using pheromone traps with Denazil-P («Schelkovo Agrokhim», Russia) to attract moth males. Two days after the first plum moth butterflies flied, 400 leaves and the same number of ovaries (after their formation) were collected from 10 trees standing evenly along diagonals of the plantation to determine the start date of egg laying. From each tree the leaves and ovaries were collected daily from four sides (10 samples per side). The beginning of caterpillar hatching was determined by daily viewing 400 ovaries, starting from day 4 after the detection of the first eggs laid. Our survey shows that northern populations of *G. funebrana* are presently widely spread and successfully adapted outside 52° north latitude previously deemed the northern border of plum moth area. In Central Non-Chernozem Zone, particularly in the Moscow region (55° north latitude), the pest is capable to produce not one but two generations if sum of effective temperatures (SET) above 10 °C is 854-1124 °C. This is much lower than the value for the forest-steppe zone in Ukraine (1231-1353 °C). In some years the second *G. funebrana* generation exceeds the first generation in abundance. The start date of the overwintered generation flight varies greatly depending on the weather conditions during spring. The favorable sum of effective temperatures is from 59.4 to 159.8 °C which coincides with flowering and ovary formation in plum trees. So SET values and phenophases of plant development are not reliable reference points to forecast the beginning of the butterfly flight. Unlike geographical populations of *G. funebrana* from the southern and central zones of horticulture, butterflies of northern *G. funebrana* population remain active at daily air average temperature of 11-14 °C. This study indicates that in the northern gardening protective measures should be planned against both the first and second generation of plum fruit moth to prevent mass damage to fruits and to reduce the number of overwintering *G. funebrana* population

Keywords: *Grapholitha funebrana* Tr., northern populations, pheromone traps, the sum of effective temperatures, the dynamics of the flight

Climate changes over the last decades, as well as the lengthening of the vegetation period, lead to an imbalance in the habitat of living organisms, disrupting the order of the relationship between them [1-4]. Weather anomalies, temperature rise, shifts in precipitation, causing fluctuations in other environmental factors, to which living organisms react depending on their inherent ecological plasticity and adaptive capabilities, cause qualitatively new transformations in ecosystems [(5-8]. Similar dynamics can be observed in agroecosystems, including horticultural plantations. The impact of climate changes on these systems has been evident since the early 1980s [9-11].

Climate warming, on the one hand, promotes a number of crops grown in the southern and middle zone of horticulture, in the Northern regions, on the other hand – leads to the penetration of harmful organisms to new territories. In particular, in the Central Non-Chernozem Zone, noticeable changes occur in the bio-ecology of phytophages and pathogens, the period of their harmfulness is lengthened, new, unusual to the region, pests and pathogens occur, those pests which previously had secondary importance are activated. The emergence of new varieties and modifications of cultivation technologies favor this process [11-13].

The species composition of plum pests, the degree of their danger and economic significance is exposed to significant metamorphoses. Thus, the damage of the fruit by plum moth (*Grapholitha funebrana* Tr.) and crop losses from this phytophage in different regions [14, 15] are up to 80% or more, and to ensure the profitability of crop production, it is necessary to apply at least 3-4 chemical treatments for the growing season [16-19]. To control numbers and prevent crop losses from moth, the environmentally friendly methods of struggle, including breaking chemical communications, pheromone confusion and mass trapping of males [20-22], the use of oophages [23] based on monitoring of pest population are offered [24]. However, the features of bioecology and related harmfulness of the phytophage in the Central Non-Chernozem Zone are still not investigated.

In this paper, it was first established that the plum moth is widely distributed in the Central Non-Chernozem Zone and develops here in two generations. The limits of the sum of effective temperatures for the beginning of flying of butterflies of the overwintered generation, the formation of two generations, the beginning of egg laying, and the pest caterpillar hatching are determined. The minimum air temperature for the active swarming of the Northern population butterflies and the dynamics of swarming during the vegetation period, which differ significantly from the indicators for the southern zone, were established.

The work objective was to study the bioecology of plum moth in the Central Non-Chernozem Zone and assess the dynamics of this phytophage during the growing season.

Techniques. The study was carried out in the fruit-bearing plum plantations (the laboratory lot and the demonstration garden) of All-Russian Horticultural Institute for Breeding, Agrotechnology and Nursery (ARHIBAN, Moscow Region, Leninsky District) in 2015-2017. The swarming dynamics of *G. funebrana* population was monitored using the pheromone Atrakon-A traps of the triangular form (AO Shchelkovo Agrokhim, Russia) with the size of the adhesive liner 10×17 cm. To attract males, the pheromone Denazil-P (AO Shchelkovo Agrokhim, Russia) was used with a dispenser, the rubber capsule impregnated with the active substance (sex pheromone) Z8 (dodecyl acetate, 1 mg/dispenser). Pheromone traps were hung at a height of 2 m directly in front of flowering plum varieties of early maturing (Utro, Opal, Skoroplodnaya). Dispensers were placed in the center of the adhesive liner with a tweezer, changed every 6 weeks (adhesive liners were replaced as contaminated). Inspection of pheromone traps and the counting of the caught males before the first butterflies flew were carried out daily, at the end of swarming of the 2nd generation (since the beginning of the 2nd ten-day period of September) in 1 day, and then 2-3 times a week. Dispensers were stored in the refrigerator before use.

To establish the start date of egg laying by females in 2 days after the flight of the first butterflies from 10 trees evenly distributed over two diagonals of planting, 400 leaves and the same number of ovaries (after their formation) were selected. The selection was carried out daily, on 10 pieces from four parties of each accounting tree. The samples were viewed (microscope MBS-10, OAO LZOS, Russia). The beginning of caterpillar hatching was determined on a daily basis (starting 4 days after the detection of the first eggs of the phytophage) scanning for 400 ovaries.

The mean by dates of observations (sample mean $\bar{x}$) and the standard deviation for each observation site (σ) were calculated. The correlation between the number of males of the 1st and 2nd generations of plum moth and the sums of effective temperatures in the period of intensive swarming (SET 1 and SET 2) was analyzed according to B.A. Dospekhov [25] using the Microsoft Excel software package. Correlations were considered statistically significant with confidence probability P = 99%.

Results. In the period from the late 1980s to the early 1990s, 52° of Northern longitude was considered the Northern boundary of the *G. funebrana* distribution and within the Orel, Kursk, Voronezh Regions and the Northern part of the Belgorod Region, the pest developed in I generation [26-28]. However, nowadays, the plum moth has penetrated and intensively develops in the Central Non-Chernozem Zone, including in the Moscow Region (55° of Northern longitude). Even in the abnormally cold growing season 2017 (Table 1), it gave not one, but two generations.

1. Indicators of the average temperature and precipitation for the vegetation periods of 2015-2017 in the Leninsky District of the Moscow region (according to the weather station of the Domodedovo Airport, Moscow Province

Parameter	Year	Month					
		April	May	June	July	August	September
		Average temperature, °C					
Long-term		6,7	13,2	17,0	19,2	17,0	11,3
Actual	2015	6.1	14.3	18.0	18.1	17.6	13.8
	2016	8.1	15.0	18.2	20.9	19.5	11.4
	2017	5.3	10.9	14.5	17.9	18.8	13.0
Deviation	2015	–0.6	+1.1	+1.0	-1.1	+0.6	+2.5
	2016	+1.4	+1.8	+1.2	+1.7	+2.5	+0.1
	2017	–1.4	–2.3	–2.5	–1.3	+1.8	+1.7
		Precipitation, mm					
Long-term		37	50	80	85	82	68
Actual	2015	44	119	94	121	14	88
	2016	34	63	61	122	167	59
	2017	79	84	140	105	68	38
From long-term, %	2015	119	238	117	142	17	129
	2016	92	126	76	144	204	87
	2017	214	168	175	124	83	56

Certainly, the temperature regime, in particular, the sum of effective temperatures (SET) has a dominant effect on the rate of phytophage development in different phases, but precipitation, humidity, and a combination of these factors also have a significant impact. The development dynamics of plum moth in stable warm weather during the growing season is smoothed. That is, for each generation, the beginning of swarming, one peak, and the decline in numbers is clearly distinguished, as it was noted in Northern Italy, the southern part of Bulgaria [29, 30], a number of regions of the Czech Republic and Slovakia [31]. The models of development dynamics of moth developed in these conditions concerning the sum of effective temperatures well correlate with the actual situation in a concrete zone [29], but cannot be universal for regions where climatic and geographical conditions differ essentially [31].

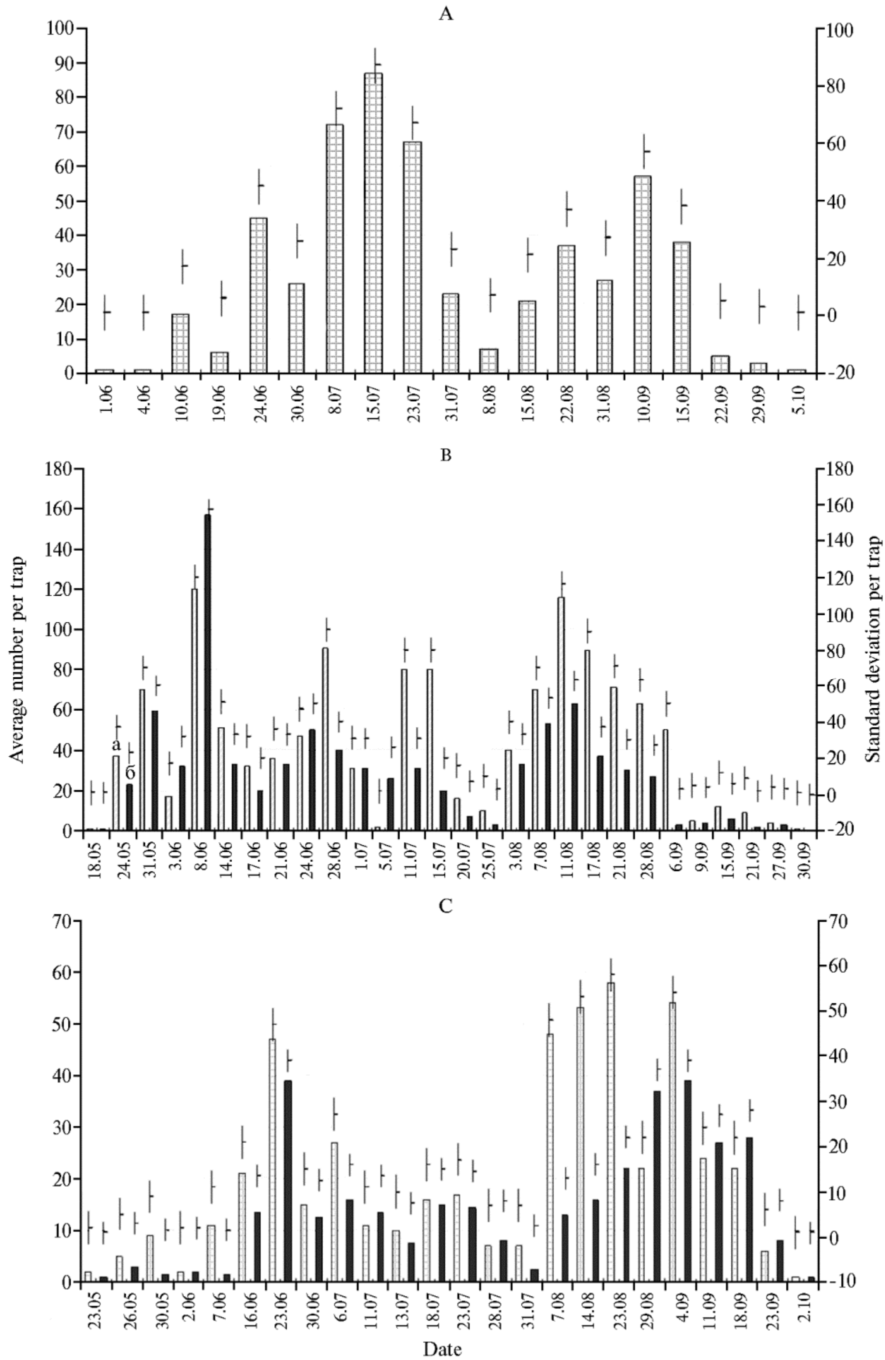
In the Northern regions, depending on the weather conditions of the year, more complex development dynamics of *G. funebrana* is observed, often with several periods of increase and decrease in population during the swarming period of one generation, which is noted from the forest-steppe zone of Ukraine [30, 32]. In contrast to the southern and middle horticulture zones, where the sum of effective temperatures by the beginning of swarming of the overwintered generation of butterflies has more or less similar indicators over the years, in the Central Non-Chernozem Zone, they vary greatly. In the 1980s, swarming of the moths of the overwintered generation *G. funebrana* began with the accumulation of SET above 10 °C in the range of 105-120 °C [28]. According to I.V. Shevchuk et al. [30], in the forest-steppe zone of Ukraine, butterflies of the overwintering generation fly when SET is 45.5-47.0 °C, and in Bulgaria, this is 32.6-67.6 °C. In comparison with the beginning of the 1960s, in the Northern forest-steppe zone of Ukraine, butterflies fly 33-36 days earlier, and swarming ends much later, in early or mid-October. The authors explained it with the global climate changes.

According to the authors' data, in 2015, SET higher than 10 °C at the beginning of swarming of butterflies *G. funebrana* was 159.8 °C (the 1st of June), in 2016 – 86.9 °C (the 18th of May), in 2017 – 59.4 °C (the 23rd of May). The beginning of butterflies swarming also varied significantly over the years and accounted for the phenophase of the flowering beginning, the end of flowering or the ovaries formation of later varieties of plums Pamyat Timiryazeva, Renklod Tambov, Aleksii. The maximum and minimum SET indicators for 3 years differed 2.7-fold. The time of egg laying by females of pests also varied year by year (on 2015 June 4 at SET of 185.6 °C, on 2016 May 24 at SET of 105.4 °C, on 2017 May 30 at SET of 102.6 °C) and the beginning of hatching of the first caterpillars (on 2015 June 12 at SET of 240.1 °C, on 2016 June 3 at SET of 191.2 °C, 0n 2017 June 16 at SET 147.7 °C).

This indicates high ecological plasticity of the phytophage, which promptly reacts to the actual changes in the environment and optimally harmonizes its development, on the other hand this fact points to a continued adaptation within the new area. In the conditions of sharp climatic changes, typical for the Non-Chernozem Zone of Russia, the determination of the beginning of plum moth swarming only by SET does not guarantee high enough accuracy and can serve as a guide for planning, but not carrying out protective measures, as well as the phenophase of plant development. Other climatic factors, including the difference between day and night temperatures, their value and distribution by day, intensity and duration of precipitation, the presence and strength of the wind, etc., have a significant impact on the dynamics of the phytophage development. More reliable information on the dynamics of butterflies swarming can be obtained by pheromonitoring [20, 21], and measures to protect the crop from the pest should be carried out on the totality of the data obtained [24], including the results of visual observation.

Plum moth swarming in 2015 lasted for 127 days, in 2016 for 136 days, in 2017 for 132 days, which is more than 4 months (Fig.). The period of flight of the overwintering generation of moths took about 1.5-2 months. In 3-5 days after the flight, females began to lay eggs. The duration of the embryonic development period and development of caterpillars, depending on weather conditions, was from 1 week to 12 days and from 17-20 days to 1 month, respectively. It is known that the development at the pupal stage needs 1.5-2 weeks, and the life expectancy of butterflies in different conditions varies from 4-5 to 15 days [26-28].

In case of only one generation, the number of butterflies could not significantly increase after mid-August—early September and swarming could not continue until the beginning of October. Thus, in the conditions of the Central Non-Chernozem Zone, the plum moth gave not one, but two generations in a year. The second generation could be complete or optional depending on weather and fodder supply.



Plum moth (*Grapholitha funebrana* Tr.) swarming in 2015 (A)**, 2016** (B)**, and 2017** (C) (number on average per 1 trap) **at a laboratory plot** (a) **and in the demonstration garden** (b) ($x \pm \sigma$, the Leninsky District, Moscow Province).

In 2015-2016, the weather conditions favored the development of *G. funebrana* of the 1st and 2nd generations, but the period of maturation and harvest came much earlier than in 2017. In these conditions, the 1st generation was more numerous. It is particularly explained by the fact that even in the southern regions from 25 to 55% of the caterpillars of each generation go to the winter diapause (certainly, except for the last generation, which is completely diapaused) [28].

In 2017, despite the abnormal for this period cold that lasted till mid-summer, combined with prolonged heavy rains (see Table 1), butterflies swarming began on May, 23, lasted continually. Butterflies of the 1st (overwintered) generation reached the maximum number in pheromone traps in late June—early July (see Fig.). The relatively high number fluctuated depending on weather conditions (with two peaks), but remained until the middle of the third ten-day period of July. Then, it decreased to the middle of the 1st ten-day period of August, reaching its minimum. However, the process was not interrupted and intensified with the beginning of butterflies swarming of the 2nd (summer) generation. During this period, the weather changed quickly: precipitation was less; the air temperature was much higher than the average annual data. In these conditions, the majority of caterpillars of the 1st generation did not diapause, and gave rise to the second generation of the plum moth. As a result, it was more numerous than the first generation. Along with the change in weather, this was facilitated by the abundant fodder supply, since the ripening and harvesting period was delayed by about 3 weeks, and in late varieties, the fruits remained until the beginning of October. The high number of butterflies of the 2nd generation (also with two peaks) was noted until the second half of the 2nd ten-day period of September with changes depending on weather conditions. Further on, the number of pests constantly and sharply decreased, and the last butterflies were found in late September—early October.

In the abnormal weather conditions of spring and the first half of summer 2017, some important features in the pest bioecology were found. Butterflies maintain swarming activity at an average summer air temperature of 11-14 °C. In early June, when average daily air temperature fell below 10 °C and did not rise above 12.9 °C, they did not interrupt swarming unlike the traditional pest in this area, the apple worm *Cydia* (*Laspeyresia*) *pomonella* L. (its swarming was not observed).

It was found that in the Central Non-Chernozem Zone with the accumulation of SET above 10 °C to 854-1124 °C developed two generations of plum moth – overwintered and summer. Similar indicators for the forest-steppe zone of Ukraine are 1231-1353 °C [30], which emphasizes the high ecological plasticity of *G. funebrana*. The value of SET 854 °C was recorded in 2017, when the 2nd generation was superior to the overwintered generation in number. However, it should be emphasized that in 2017, the SET during the intensive swarming of the summer generation by 148.7 °C exceeded the value of the SET in the period of the intensive swarming of the overwintered generation (in 2015 and 2016 by 10 and 7.3 °C, respectively). The analysis of the multiple correlations between the number of the 1st and 2nd generations in the period of intense swarming and the corresponding values of SET also showed a closer relationship between the number of the summer generation and SET 2 (Table 2). This research found average strength positive correlations between the numbers of the 1st and 2nd generations, as well as SET 1 and the number of the 2nd generation. At high SET 1 (within the optimal temperature for the phytophage 23-29 °C), the development accelerated and caterpillars that have completed the nutrition earlier could pupate and give rise to the second generation. The decrease of SET 1 shifted the formation and maturation of the crop to a later date, that is, it influenced the fodder base (taking into account the varietal factor, the activity of entomophages and entomopathogens) and in combination with a higher SET 2 stimulated pupation of caterpillars and the flight of butterflies of the second generation.

2. Correlation between SET 1, SET 2 and the number of male plum moth (*Grapholitha funebrana* Tr.) of the 1st and 2nd generations (Moscow Province, 2015-2017)

Indicator	1st generation	2nd generation	SET 1	SET 2
1st generation	1			
2nd generation	0.4361*	1		
SET 1	0.3740*	0.5741*	1	
SET 2	0.2492	0.5923*	0.4701*	1

N o t e. SET 1 and SET 2 — sums of effective temperatures above 10 °C in the periods of intense swarming of butterflies of the 1st and 2nd generations.
* Correlations are statistically significant with confidence probability P = 99%.

Certainly, bioecological development of any organism in a particular environment are determined by the interaction of a set of factors, each of which deserves special attention, but a more significant role is played by the dominant. By using data on the initial number of the phytophage and its relationship with the SET indicators, it is possible to predict and pre-plan the necessary protective measures, but their multiplicity and specific timing should be established taking into account the results of pheromonitoring.

Thus, the plum moth *Grapholitha funebrana* Tr. in the Central Non-Chernozem Zone of Russia develops not in one, but in two generations. The beginning of swarming of butterflies in the overwintered generation depends on spring weather conditions, strongly fluctuates on years and occurs at SET above 10 °C from 59.4 to 159.8 °C (from the beginning of flowering to plum ovaries formation). Two-generation development of *G. funebrana* in the Central Non-Chernozem Zone requires SET above 10 °C within 854-1124 °C, and butterflies swarming can continue at 11-14 °C. The second generation of *G. funebrana* in some years may exceed the first one in number, which requires appropriate measures to combat the pest. This will ensure crop preservation and the high fruit quality, also significantly reducing number of overwintering population.

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