Soybean moth *Leguminivora glycinivorella* (*Lepidoptera: Tortricidae*): harmfulness in the conditions of the south of the Amur region

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**Abstract.** The research paper presents data on the particularities of the spreading *Leguminivora glycinivorella* within the field, the degree of damage to various soybean varieties of Russian selection by this pest, as well as calculations of the economic threshold of harmfulness based on current data. Pest infestation of crops occurs from the near edge part; maximum density is achieved in a zone of 10-20 m from the edge of the field. The most susceptible to pest infestation are pods of varieties with a growing season of up to 102 days, and varieties with a growing season of more than 122 days are the least vulnerable. *L. glycinivorella* reaches the economic threshold of harmfulness at 10.5-13.4% of infected pods, provided that a seed soybean yield is obtained, as well as when obtaining vegetable soybean that is used for food in pods. The use of insecticides in the cultivation of soybean, intended for processing, is inadvisable at any level of reproduction of the pest.

**1. Introduction**

Damage to the generative organs of soybean by pests leads not only to yield losses and decline in the quality of processed products, but also reduces seed germination and increases their vulnerability to fungal diseases.

Five species of lepidopterans family (*Lepidoptera Linnaeus, 1758*) that feed on pods and seeds in the larval stage are mentioned in the literature: noctuid moths *Pypphia umbra* (Hufnagel, 1766), *Protoschinia scutosa* (Denis & Schiffermuller, 1775), *Heliothis adaucta* (Butler, 1878), *H. ononis* (Denis & Schiffermüller, 1775) and soybean moth - *Leguminivora glycinivorella* (Matsumura, 1898) [1]. Previously, efforts were already made to determine the degree of harmfulness of this pest group, but most of the works is significantly outdated [2], moreover they were carried out with varieties that are currently out of circulation [3]. At present, research is conducted to determine the genetic diversity of populations of various living organisms, including soybean moth [4]. Work is underway to improve methods for detecting and recording pests. The method of pheromone traps shows the greatest success in this area [5, 6]. There are also known attempts to create and improve methods for predicting the pest population [7, 8].

The goal of this work was to study the dynamics of spreading soybean moth in soybean crops, features of phenology, the reaction of varieties and variety samples of the Amur selection to pest infection, as well as the economic threshold of harmfulness in the conditions of the south of the Amur region.
2. Materials and methods

The monitoring of spreading and harmfulness of lepidopterans, which damage the generative organs of soybean, was conducted for three years in the Amur region. In 2017, reconnaissance and route investigations were carried out, and in 2018 and 2019 - detailed records on the experimental fields of Federal State Budget Scientific Institution All-Russian Scientific Research Institute of Soybean in Sadovoe village of Tambov district [9]. In all experimental fields, we identified three species: *P. umbra*, *H. adaucta* and *L. glycinivorella*. Caterpillars of noctuid moths *P. umbra* and *H. adaucta* were found singly in different parts of the field. It is difficult to evaluate their economic value, since the share of seeds damaged by them accounted for no more than 0.01% of the total number of all damaged seeds.

The main pest that damages the generative organs of soybean in the Amur region is soybean moth (*L. glycinivorella*). To test the vulnerability of varieties by caterpillars of lepidopterans, at least 300 pods were selected from plants located in a single line from the edge to the center of the field, provided all pods were collected from one plant and from at least five plants per meter.

3. Discussion and results

Soybean moth has a long diapause. Pupation of caterpillars that left soy pods occurs in the soil at a depth of about 10-12 mm. The pupa is at rest from the beginning of September until the beginning of July of the following year. According to research, *L. glycinivorella* falls into diapause at the length of daylight shorter than 15 hours [4], however, these data indicate the flight ending of imago, but not its beginning, since they do not take into account the relationship between the flight of the butterfly and the soybean phenophase R5, during which the most massive egg-laying by pest occurs. According to our observations, even a single moldboard plowing destroyed most of the pupae, therefore, the spread and infection of the pods by soybean moth began from the edge of the field in all noted cases. The maximum density of soybean moth was marked at sites located 10–20 m from the boundary occupied by perennial grasses. Immediately after leaving the pupae, the butterflies move relatively slowly towards the center of the field. These data are consistent with previous observations and confirm information obtained in Japan [10, 11].

According to the results of testing 30 soybean varieties and 8 variety samples for infection by the moth, they were divided into 4 groups with different growing season, after which the infection of each group was analyzed (figure 1).

Group 1. The growing season of 95-102 days – 5 varieties. Infection of all varieties with caterpillars of the moth exceeded 6%, more than 10% of the pods were infected in 4 varieties. The most vulnerable variety is Topaz (growing season of 93 days – 13.7% of the infected pods), the least one is Gratsiya variety (94 days, 7.7%).

Group 2. The growing season of 103-110 days – 15 varieties and variety samples. One variety exceeded 8% of infection, 7 varieties and variety samples exceeded 6%, 2 varieties did not reach 3%. The most vulnerable varieties: Zhuravushka (106 days – 8.2%), Dauriya (106 days – 7.9%), Sonata (110 days, 7.5%). The least vulnerable: Kukhanna (109 days – 2.2%) and Persona (106 days – 2.4%).

Group 3. The growing season of 111–117 days – 15 varieties and variety samples. 3 varieties exceeded 6%, 4 varieties and variety samples did not reach 3%. The most vulnerable varieties: Lazurnaya (112 days – 7.7%), Lebyodushka (112 days – 7.6%). The least vulnerable varieties: Divnaya (111 days – 2.5%), Kitrossa (114 days – 2.7%) and variety samples: AM-1170 (112 days – 2.5%), Tat’yana Ryazantseva (112 days – 2.6 %).

Group 4. The growing season of 122–124 days - 3 soybean varieties and variety samples. None of the varieties and variety samples had an infection rate of 6%, 2 varieties did not reach 3%. The most vulnerable variety sample is AM-2423 (122 days – 3.7%). The least vulnerable: variety sample AM-2343 (122 days – 1.7%) and variety Koloritnaya (124 days – 2.2%).
Figure 1. Degree of infection of soybean varieties and variety samples (%) depending on the growing season (days).

In this experiment the percentage of infected pods tends to be inversely related to the duration of the growing season, however, in each group there is a range of variability from the most vulnerable varieties to the most resistant ones. Modern scientists are of the opinion that varieties with poorly developed downiness of pods, the moths infect less actively [12]. In this regard, the variety Gratsiya is of greatest interest. Having a growing season in the range of 90-97 days (on the average of 94 days), this variety belongs to the early-ripening group. At the same time, the percentage of infected pods (7.7%) is significantly lower than the other early-ripening varieties and is at the level of mid-ripening varieties, such as Lazurnaya (7.8% of infected pods with an average growing season of 112 days), Dauriya (7.9% at 106 days) and Lebyodushka (7.7% at 112 days).

Despite the fact that the caterpillars of soybean moth need on average the same amount of nutrition to reach the last age, the loss in weight of damaged seeds varies in a very wide range and does not have a pronounced dependence on the size of the seeds. This phenomenon is explained by the individual features of the reaction of various varieties to seed damage by L. glycinivorella caterpillar. In case of damage, part of the seeds is ripened, reaching its full weight considering the loss of damage, the other part stops growing and dries out (figures 2 and 3). The ratio of these parts is varying in different varieties and variety samples. The reaction of seeds to damage influences the loss in weight, which ranges from 10-15% of the seed weight in varieties with predominantly ripening seeds and 50-60% of the seed weight in varieties with predominantly drying out seeds. When damaged by soybean moth, the lowest loss in seed weight is noted in the varieties: Sentyabrinka - loss of 10% in the seed weight, Gratsiya - 11%, Charodeyka - 15%. The greatest one in varieties: Koloritnaya – loss of 61% in the seed weight, Alyona - 58%, Kitrossa - 52%. The average loss in weight for all 38 varieties and variety samples was 32.7%.
To determine the protein and oil content, the seed samples of healthy and damaged seeds of the varieties Garmoniya, Umka and Lidiya were selected, which had sufficient weight for analysis. The results of the analysis showed that the oil content in damaged seeds decreases on average by 2.8% relative to healthy seeds, but the protein content increases by 2.2%. These minor and mutually compensating changes in the chemical composition of the seeds give reasons for excluding the loss of protein or oil as an additional factor in calculating the harmfulness of L. glycinivorella.

The formula for calculating the loss in weight proposed by Engelgardt and Mishchenko does not include part of the preliminary calculations [2], so the above mentioned formula was recognized by the authors as unsuitable for use, and the original procedure was used in calculating the loss in weight of damaged seeds.

The following variables are needed to calculate the loss in weight: number of healthy seeds in the sample \( a \), number of damaged seeds in the sample \( b \), weight of all healthy seeds in the sample \( m_1 \), weight of all damaged seeds in the sample \( m_2 \). The average weight of one healthy seed \( X_{wh} \) is preliminarily calculated using the equation (1):

\[
X_{wh} = \frac{m_1}{a}
\]  

In a similar way, the average weight of one damaged seed \( X_{wd} \) is calculated by equation (2):

\[
X_{wd} = \frac{m_2}{b}
\]  

Having these two calculations, it is possible to calculate the average difference in the weight of one healthy and one damaged seed \( X_d \) by equation (3):

\[
X_d = \frac{m_1}{a} - \frac{m_2}{b}
\]  

Product of the obtained value by the number of damaged seeds will allow obtaining a weight loss in grams \( X_{wl} \) according by equation (4):

\[
X_{wl} = \left( \frac{m_1}{a} - \frac{m_2}{b} \right) \times b
\]  

For further calculations, it is necessary to calculate the weight of the sample, as if it all consisted of healthy seeds. This operation is necessary to obtain the most accurate information about weight loss as a result of damage to the seeds. Since the total weight of the entire sample does not include the loss in weight proper, this value will give an error in the calculations, therefore, cannot be used in the calculations. The total weight of the sample, as if it all consisted of healthy seeds \( X_{tw} \), is a product of
the total number of seeds in the sample by the average weight of one healthy seed and is calculated by the equation (5):

$$X_{tw} = \frac{(a + b) \times m_1}{a}$$

(5)

This value is taken as 100% of the weight of the entire sample. Having all the data, it is possible to calculate the percentage of loss in weight by the equation (6):

$$X = \frac{(\frac{m_1}{a} - \frac{m_2}{b}) \times b}{((a + b) \times \frac{m_1}{a}) \times 0.01}$$

(6)

where:
- $a$ – number of healthy seeds in the sample (pieces).
- $b$ – number of damaged seeds in the sample (pieces).
- $m_1$ – weight of healthy seeds in the sample (g).
- $m_2$ – weight of damaged seeds in the sample (g).
- $X$ – loss in weight (%).

In general, the net loss in weight for all varieties was 1.291%. In the group of varieties with a growing season of 92-102 days, this indicator was on average 0.673%, in the group of 103-110 days – 1.224%, in the group of 111-117 days – 1.294%, in the group of 122-124 days – 0.965%. The same characteristic for some vulnerable varieties was: Topaz – 2.754%, Lidiya – 2.640%, Kruzhevnitsa – 2.934%, Sentyabrinka – 0.763%, Zhuravushka – 1.937%.

In this article, the term “Economic threshold of harmfulness” (ETH) is used in accordance with the work of A. I. Afanas’eva et al. [13], where ETH is understood as: “... such a pest population density... at which the cost of protective measures is paid off by preserving the yield no less than once”. It should be understood that the profit from the use of plant-protecting agents can be obtained only if ETH is exceeded, but not when it is achieved; in addition, when calculating ETH, the chemical load on farmland and adjacent territories is not taken into account. At the extension in flight time of soybean moth and its secretive way of life, record of imago is possible only by using pheromone traps. However, pheromone traps mainly attract males [5], and their effectiveness largely depends on weather and climatic conditions, therefore, in most cases, another method is used to estimate the number of pests, namely, calculating the percentage of pods populated by caterpillars. In the literature, there have been noted cases of multiple infections of pods, up to four caterpillars in one pod [2], however, in the experiments of 2017-19 at all stages of maturation, no more than one L. glycinivorella caterpillar was found in each infected pod. Based on the latest data, the number of caterpillars of soybean moth coincides with the number of pods infected by them, therefore, the last indicator can be considered equivalent to the first one and used to determine ETH. In the years of the greatest reproduction of the pest and the multiple infections of pods, the number of caterpillars should be taken into account.

ETH was calculated in the conditions of the Amur region, depending on the yield according to 4 variants (1.0; 1.4; 1.8; 2.5 t/ha) as a result of the use of insecticide (active ingredient - Cypermethrin at a concentration of 250 g/l of microemulsion with a consumption rate of 0.3 l/ha) with a minimum efficiency (reduction of pod damage by 17.5%), average (20.0%) and maximum one (22.2%) [14]. Under the conditions of removing seeds of all degrees of damage, the calculations were carried out for the seed soybean to a state of self-repayment, that is, up to equalize the costs of using the insecticide with the cost of obtained yield increase as a result of its application. At the same time, the average sell price of 1 ton of soybean, prevailing for 2015-2019, was adopted, namely, 294.49 dollars per ton and average costs for purchasing insecticide, fuel and lubricants, amortization, wear technology, employee wages and other expenses amounted to 10.27 dollars per hectare (calculated at the exchange rate of the US dollar as of March 13, 2020).

When calculating ETH of soybean intended for deep processing, only the net loss in weight of damaged seeds is taken into account. The amount of expenses for pesticide application in 10.27 dollars equals 34.9 kg of the conserved soybean mass. If the effectiveness of insecticide is 17.5%, the total
weight loss should be 199.4 kg/ha in this case. Since, on average, for all studied varieties and variety samples, the weight of grains damaged by the caterpillar of moth is lower by 32.7% than the weight of uninjured ones, the costs of insecticide application begin to equalize with the cost of its application when the weight of all damaged seeds is 608.6 kg. If we take for example the yield of 1 t/ha, this weight will be 60.8% of the total crop. On average, 1 infected pod contains 1.90 damaged seeds (80.85%) and 0.45 healthy (19.15%) seeds. Therefore, with a yield of 1 t/ha and a minimum insecticide efficiency of 17.5%, equalization of the costs of insecticide application with the profit obtained from its application will not occur even if 100% of the pods are infected. With a maximum drug efficiency of 22.2% and a yield of 2.5 t/ha, the same value is about 37% of infected pods. The calculation of ETH values for seed soybean intended for processing is given in table 1.

| Efficiency of insecticide % (decrease in the number of infected pods) | % of infected pods at yield, t/ha |
|---|---|---|---|---|
| 22.2 | 91.3% | 65.1% | 50.5% | 36.6% |
| 20.0 | 101.4% | 72.3% | 56.1% | 40.7% |
| 17.5 | 115.9% | 82.7% | 64.1% | 46.5% |

When calculating ETH for seed soybean, any damage to the seed by the caterpillar of moth leads to its loss. As a result of damage by the moth, weight loss is not taken into account in this case. Thus, sum of 10.27 dollars is equal to 34.9 kg of the preserved soybean seeds. With an insecticide efficiency of 17.5%, the total grain loss should be 199.4 kg/ha or 19.94% of the total mass of the yield with a crop yield of 1 t/ha, which gives ETH about 25% of the infected pods. With a maximum drug efficiency of 22.2% and the yield of 2.5 t/ha, this same value is about 8% of the infected pods. The calculation of ETH values for seed soybean is given in table 2.

| Efficiency of insecticide % (decrease in the number of infected pods) | % of populated pods at yield, t/ha |
|---|---|---|---|---|
| 22.2 | 19.4% | 13.9% | 10.7% | 7.8% |
| 20.0 | 21.6% | 15.4% | 11.9% | 8.7% |
| 17.5 | 24.7% | 13.9% | 10.7% | 7.8% |

In the countries of East and South-East Asia, there is a tradition of collecting unripe soybean, cooking them in green pods and eating them (“Maodou” in Chinese 毛豆, “Edamame” in Japanese 枝豆). In this case, all the pods, in which there are damaged seeds, are a loss of the yield. In this situation, when calculating ETH, it is necessary to take into account not only damaged soybean seeds, but also healthy seeds found in pods along with damaged ones. Thus, sum of 10.27 dollars is equal to 34.9 kg of the preserved soybean seeds, which include 80.85% of damaged seeds and 19.15% of healthy ones. With the insecticide efficiency of 17.5%, the total grain loss should be 199.4 kg/ha, of which 80.85% are damaged, which gives ETH about 16% of infected pods with the yield of 1 t/ha. With a maximum drug efficiency of 22.2% and the yield of 2.5 t/ha, the same value is about 5% of infected pods. The calculation of ETH values for seed soybean is given in table 3.

The research results are good consistent with the literature data: reference book “Economic thresholds of harmfulness of pests, diseases and weeds in agricultural crops” (10% of populated pods) [15] and methodical manual “The Most Common Soybean Pests in the Amur Region and Measures for Their Control” (8-10 eggs/100 pods) [14]. However, this ETH value is applicable only in the case of yields of 1.5 t/ha and higher, as well as the efficiency of pesticide from 20% or more, and only if it is
necessary to obtain seed or vegetable soybean. The use of insecticides in the cultivation of soybean, which is further used as fodder or technical raw materials, is economically unjustified.

Table 3. The proportion of pods infected with soybean moth (%), at which the use of insecticide is paid off by the cost of preserved yield (vegetable soybean).

| Efficiency of insecticide % (decrease in the number of infected pods) | % of populated pods at yield, t/ha |
|---------------------------------------------------------------|----------------------------------|
|                                                               | 1.0 | 1.4 | 1.8 | 2.5 |
| 22.2                                                          | 12.7% | 9.1% | 7.0% | 5.1% |
| 20.0                                                          | 14.1% | 10.1% | 7.8% | 5.7% |
| 17.5                                                          | 16.1% | 11.5% | 8.9% | 6.5% |

4. Conclusions

Pest infestation of crops begins from the near edge part of the field, reaching its central parts 10-14 days after the start of flight. The maximum density of the pest is noted at 10-20 m from the boundary.

As a whole, the degree of infection of pods in soybean varieties and variety samples tends to be inversely related to their growing season, but individual vulnerability overrides the general trend. In soybean varieties and variety samples with a growing season from 90 to 102 days, 7.7-13.7% of pods were infected, from 103 to 117 days – 2.2-8.2%, from 122 to 124 days – 1.7- 3.7%.

When the seed damaged by L. glycinivorella, the loss in weight varies widely on average for all tested varieties and variety samples of the ARSRI of Soybean selection and it is on average 32.7% of the seed weight for 38 varieties and variety samples. This value depends on the individual reaction of the variety to damage. When drying out, the damaged seed loses up to 50-60% of its weight. When the damaged seed is ripened, the loss in weight is 10-15%. Damage to seeds by soybean moth only slightly influences the ratio of protein and fat in them, without reducing their share in the weight of the seed, therefore, when calculating the harmfulness of L. glycinivorella, these indicators do not matter.

When using a soybean yield as a raw material for deep processing or for fodder purposes, the use of insecticide is not paid off with its efficiency at any yield values. When obtaining varietal soybean, the use of insecticides begins to pay off one time, if the infection of pods is 8-10% with the yield of 1.8 t/ha and higher. When obtaining vegetable soybean, the use of insecticides begins to pay off one time, if the infection of pods is 8-10% with the yield of more than 1.4 t/ha.

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