Biology of broadbean seed beetle (*Bruchus rufimanus*; Coleoptera: Chrysomelidae) in Latvia

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### ABSTRACT

The broadbean seed beetle (*Bruchus rufimanus* Boheman, 1833) is a major pest of faba bean (*Vicia faba* L.) almost everywhere this crop is grown. The main tasks of this research were to study the seed beetle’s phenology, and rates of egg laying, larval survival and the emergence of young adults before the harvest. Studies were done in field conditions in farms located in various places in Latvia. The highest density of imagines was observed at a time when the plants were flowering intensively. Egg laying began as soon as the pods had formed in the lower third of the stem and lasted 4–5 weeks. In severe infestation happened, more than 34 eggs were laid per pod. The percentage of damaged yield increased in proportion to the average number of eggs laid on pods until this number reached 11–12 eggs per pod and remained at approximately the same level also when egg-laying rate was higher. In several fields, no seeds with imago exit holes were found in the samples few days before harvest, while in other sowings, the proportion of such seeds exceeded 90% of the total amount of damaged yield.

### Introduction

In Latvia, the expansion of broadbean seed beetle (*Bruchus rufimanus* Boheman, 1833) in recent years has been associated with a sharp increase in the total area sowed with faba beans (*Vicia faba* L.). Even at the beginning of the twenty-first century, neither faba beans nor similar bean species were popular crops in the country. In the period from 2000 to 2017, the total area of land sown with this legume increased from 0.1 to 42.5 thousand hectares. However, in the last 2 years, this area has significantly decreased – 25.7 thousand ha and 28.1 thousand ha in 2019 and 2020, respectively.1 Such a sharp increase in the area sown with the beans is due to changes in Latvia’s agricultural policy, which provided for the diversification of cultivated crops in order to protect the environment.

The broadbean seed beetle has long been known as a potential agricultural pest in Latvia. This species is regularly mentioned in various sources of information addressed to farmers, such as agricultural entomology textbooks (Ozols 1963; Priedītis 1996). The biology and ecology of the seed beetle are discussed in these sources, but these reviews are not very detailed. According to them, in Latvian conditions, the species is univoltine, imagines overwinter in harvested bean seeds in warehouses (partly also in field conditions), but an infestation of new sowings occurs in cases when seed infested with imagines is used. The broadbean seed beetle was noted as a significant pest in the first half of the twentieth century, when in some regions of Latvia, it caused 75–90% crop damage in faba bean sowings (Ozols 1963). However, neither in the second half of the twentieth century nor in the first decade of the twenty-first century was the seed beetle considered to be a major pest causing significant damage. But the situation has changed in the last 10 years. Starting from about 2012–2013, reports were received from farmers about significant yield losses, and currently, the seed beetle is considered to be the most important pest of faba beans in Latvia. It is estimated that without control measures, this pest could cause yield losses of 70–100%.

The broadbean seed beetle is a widespread beetle species in Europe that is ecologically associated with various legumes (Fabaceae). In many countries, the broadbean seed beetle is a major agricultural pest due to large-scale infestations of faba beans. However, this beetle species can also feed on other legumes that grow both in the wild and can be cultivated for fodder, such as chickpea milkvetch (*Astragalus cicer* L.),
yellow vetch (*Vicia grandiflora* Scop.), Hungarian vetch (*Vicia pannonica* Crantz), broadpod vetch (*Vicia peregrina* L.), fodder vetch (*Vicia villosa* Roth) and others (Delobel and Delobel 2003, 2005; Jermy and Szentesi 2003). In faba bean sowings, yield losses caused by the seed beetle can vary over a relatively wide range. Depending on the variety, 10–50% of the seeds are infested, if plant protection activities are not performed (Kaniuczak 2004; Seidenglanz and Huňady 2016).

Growing of faba beans improves the properties of the soil used in agriculture. These plants attach nitrogen to the soil, dissolve insoluble phosphorus, promote soil microbial activity and soil porosity, and so on (Sharan et al. 2021). As a pre-crop, the faba bean promotes a larger and better quality yield of cereals such as wheat (Etemadi et al. 2019; Guinet et al. 2020). Also, the faba bean is an important food and fodder plant. It is an important source of proteins, fibre, vitamins, minerals and various compounds with antioxidant and anti-carcinogenic properties. The protein/carbohydrate ratio in faba bean seeds is more in favour of proteins compared to other popular legumes (Sharan et al. 2021). In areas where the beans are grown, the density and species diversity of bumblebees (*Bombus* spp.) are increasing (Beyer et al. 2020). Plant residues can be used as a renewable energy source. The fuel pellets, produced from them, are similar in caloric value to wood pellets. Emissions of various greenhouse gases from the combustion of such pellets also comply with the permitted limits (Jasinskas et al. 2020).

In private conversations with farmers, it has been established that the faba bean has lost its popularity in recent years due to the massive infestation of the broadbean seed beetle. It is also unclear to farmers how to effectively control this pest. However, neither advisory nor scientific institutions are able to provide effective advice in this area, as the current knowledge about the biology and ecology of the seed beetle is insufficient. As a result, in 2017, broadbean seed beetle research was started in Latvia with the aim to develop specific guidelines on monitoring methods for this species, economic threshold values and control strategies. The first step in these studies was to elucidate the phenology of the seed beetle development in field conditions, which is displayed in this article. Within our research, we tried to complete four tasks: to measure the incidence of each developmental stage of the broadbean seed beetle in growing degree days (GDD) after the sowing of beans (1); to study the amount of egg laying and its relationship with the thirds of the bean stems and with the proportion of damaged yield (2); to study larval survival rates (3); to determine the proportion of young individuals who leave bean seeds before harvest (4). To date, such information for the Nordic-Baltic region is either not available or obsolete.

**Materials and methods**

**Study sites**

Seven farms were chosen for our studies throughout the territory of Latvia to cover all regions and various possible growing conditions. As the farms wanted to remain anonymous, in this article, they are called study sites (or farms) A, B, C, D, E, F and G. Plant hardiness zone of sites varied from 5a to 7a. Sites were located ~50–150 km apart from one another. Observations were carried out in years 2017, 2018 and 2019. Each year, one field where field beans were sown was chosen in each site and a monitoring area was set up in each of the chosen fields. Only data from fields were crop reached technical maturity and was harvested was further used in analysis. Fields, in which crop failed to thrive or for previously unplanned reasons was used as a green manure or harvested for biomass instead of seeds, were excluded. Therefore, in 2017, data from four sites was analysed, in 2018 – six fields were used and in 2019 – all seven fields were used (Table 1).

All the studied fields were managed according to each farmer’s understanding of good farming. Complete soil tillage was performed at all study sites. Fields were ploughed (22–23 cm deep) using mould-board ploughs and tilled with other equipment according to good agricultural practice. In almost all fields, herbicide was applied once in a growing season. Weeds mostly were controlled by using ‘Basagran 480’ (bentazone), ‘Fenix 600’ (aclonyphene) and ‘Zetrola’ (propaquizafop). Insecticides were applied in less than half of all fields (Table 1), but fungicides and desiccants – in only a few cases.

**Meteorological conditions during observation period**

Overall, meteorological conditions in Latvia varied year to year during the observation period. The year 2017 was fairly typical temperature wise, compared to long-term average apart from a short atypically warm period in early April followed by temperature drop below norm in mid and late April, continuing into early May. Precipitation in 2017 was fairly normal in spring and throughout early and mid-summer; however starting from late August, the amount of precipitation exceeding the norm increased, peaking in mid-September, which was characterised by precipitation that fourfold exceeded the norm. This excessive precipitation caused problems in harvesting faba
beans as the moisture content in seeds was too high and machinery could not enter the fields because of the waterlogged soil.

The year 2018 was overall almost constantly warmer than the norm. There was a prolonged dry period starting from mid-April and continuing to early August, when precipitation consistently stayed under the norm the only exception being some above norm pre-

Table 1. Description of faba bean fields where studies on broadbean seed beetle were performed

| Code of the study site | Year | Coordinates of fields | Field area, ha | Sowing date | Variety/average number of seeds per pod | Previous crop | Insecticide use |
|-----------------------|------|-----------------------|----------------|-------------|----------------------------------------|---------------|-----------------|
| A                     | 2017 | N 56.907440, E 21.772647 | 9.1 | 20 April 2017 | Fuego/3.45 | Winter | Proteus OD (thiacloprid + deltamethrin); 0.75 L/ha; 18 June |
|                       | 2019 | N 56.90699, E 21.78059 | 1.6 | 15 April 2019 | Fuego/3.28 | Spring | None |
| B                     | 2017 | N 56.410750, E 24.099583 | 4.4 | 29 April 2017 | Fuego/3.62 | Winter | Fastac 50 (alpha-cypermethrin); 0.3 L/ha; 30 May |
|                       | 2018 | N 56.390419, E 24.132837 | 5.3 | 23 April 2018 | Boxer/3.49 | Winter | Decis Mega (deltamethrin); 0.15 L/ha; 14 June |
|                       | 2019 | N 56.389140, E 24.134856 | 1.4 | 11 April 2019 | Boxer/3.41 | Winter | Fastac 50 (alpha-cypermethrin); 0.3 L/ha; 8 May, 7 June |
|                       | 2018 | N 56.242940, E 25.768878 | 40.3 | 3 May 2018 | Fuego/3.13 | Spring | None |
|                       | 2019 | N 56.309599, E 25.894573 | 12.3 | 12 April 2019 | Fuego/3.04 | Spring | None |
|                       | 2017 | N 56.606257, E 26.920642 | 8.0 | 16 April 2017 | Fuego/3.56 | Winter | Fastac 50 (alpha-cypermethrin); 0.3 L/ha; 17 May |
|                       | 2018 | N 56.581927, E 26.928175 | 3.0 | 16 April 2018 | Fuego/2.88 | Spring | Fastac 50 (alpha-cypermethrin); 0.3 L/ha; 18 May, 0.75 L/ha; 22 June |
|                       | 2019 | N 56.656739, E 26.514967 | 6.0 | 16 April 2019 | Fuego/2.82 | Spring | Decis Mega (deltamethrin); 0.15 L/ha; 18 May |
|                       | 2018 | N 57.072283, E 26.627322 | 4.6 | 3 May 2018 | Fuego/3.38 | Spring | None |
|                       | 2019 | N 57.150176, E 26.630536 | 24.0 | 9 April 2018 | Boxer/2.50 | Spring | None |
|                       | 2017 | N 57.323625, E 25.514229 | 100.0 | 4 May 2018 | Fuego/3.35 | Spring | None |
|                       | 2019 | N 57.335704, E 25.491939 | 40.0 | 7 April 2019 | Fanfare/3.23 | Spring | None |
|                       | 2017 | N 56.822444, E 25.104917 | 9.7 | 10 April 2017 | Fuego/3.54 | Winter | None |
|                       | 2018 | N 56.826405, E 25.153691 | 30.7 | 19 April 2018 | Fuego/2.77 | Spring | None |
|                       | 2019 | N 56.826472, E 25.311056 | 12.0 | 5 April 2019 | Mix of varieties/3.22 | Spring | None |

In each field, two transects with 10 evenly spaced observation points each were established. One transect was placed parallel to an easily accessible field edge 12–24 m into the field. The second transect was positioned in a 45° angle to the first one, first observation point adjacent to the first observation point of the first transect, and pointing towards the central part of the field. The length of transects was between 100 and 200 m and was chosen so that the second transect did not exceed half of the width of the field. On each observation point, 10 bean seedlings were marked with bamboo skewers. In total, 200 plants in each field were marked (Figure 2).

Fields were visited and assessments were done in 7-day intervals throughout the observation period. Growth stages of faba beans were determined using Federal Biological Research Centre Of Agriculture and Forestry, Federal Office of Plant Varieties, and Chemical Industry scale (further in text: BBCH scale). Overwintered broadbean seed beetle imagines were counted starting from full emergence of bean seedlings (BBCH 10–14) and ending when no beetles were found on two consecutive assessments. Imagines were counted visually on marked
plants in the morning, before air temperature exceeded +15°C. Care was taken to move the plants as little as possible while counting the individuals to avoid them fleeing the plant. Broadbean seed beetle eggs on pods were counted from the beginning of pod development (BBCH 69–70) until no eggs were found on pods. In 2017, a single, randomly selected, pod from each of the marked plants was assessed and eggs were counted on the field using hand magnifying lens with 5× magnification. Pods were chosen according to their age, the most recently developed pods on the plant were used for egg assessment. During the other two seasons of our research, to compare the egg-laying intensity among lower, middle and upmost stem thirds, eggs were counted on three pods of each stem third on every marked plant in transects.

Pods were collected in 7-day intervals from faba bean plants to assess the development of broadbean seed beetle in bean seeds. Collection started from the point when the first pods had reached the variety characteristic size (BBCH 70) up to the point when maturity of seeds was reached (BBCH 89). Nine pods were collected in the vicinity of each observation point from non-marked plants. Three pods were collected from the lower third of stems, three from the middle third of stems and three from the topmost third of stems. In total, 180 pods per field were collected during each period of observations. Pods were packaged in paper bags according to transect and height in which they were collected, chilled to +4–+10°C and delivered to the laboratory, where they were opened, seeds counted and examined for marks of broad bean beetle larva entry. If an entry mark was present, seeds were dissected, insects removed, counted and their stage of development determined and registered. If an exit hole was present as well as entry hole, but no broad bean beetle was found in seed, it was recoded as an imago that has already emerged from the seed.

**Data processing and plotting**

GDD were calculated for each study place every year to combine data on broadbean seed beetle phenology in the single data set. Thus, the development of the seed beetle is analysed not according to dates, but accumulated GDD starting from the sowing of faba beans. For the calculation, meteorological data were obtained from Latvian Environment, Geology and Meteorology Centre hydro-meteorological weather station network. For each site, the closest hydro-meteorological weather station that records air temperature and precipitation (further in text: weather station), was used. Hourly data of air temperature starting from the day of sowing up to the day of the last assessment from Latvian Environment, Geology and Meteorology Centre database was used.

GDD accumulated for any assessment date within the observation period were calculated for each site and each year. The formula used to calculate GDD provided by each given day was

$$GDD = \frac{T_{\text{max}} + T_{\text{min}}}{2} - T_{\text{base}}$$

where $T_{\text{base}}=0°C$. If GDD>0, GDD for that day were equal to GDD, if GDD≤0, GDD for that day were equal to zero. To calculate GDD accumulated for assessment date, a
The sum of degree days provided by each day in range from sowing date to assessment date was taken.

For phenology plots, data from both transects were pooled for each field, and for each observation date, the mean per reporting basis was calculated. Reporting basis was a single plant in the case of overwintered broadbean seed beetle imagines and a single pod for the number of eggs, larvae, pupae, imagines still in seed and imagines that had emerged from the seed. Means obtained were plotted against GDD accumulated from the sowing date up to the date of assessment. Each stage of development of the seed beetle was plotted separately on a scatterplot and a trend line was added. The trend line was generated by fitting a local polynomial regression. The smoothing parameter was set to 0.75 and the degree of polynomial to 2. Tricube weighting was used. The R 3.6.1 and package ggplot2 3.2.1 was used for these purposes.

Other data were summarised using MS Excel 2016 with XL Toolbox version 7.3.4., and SPSS 22.0. One-way ANOVA and Bonferroni–Holm post hoc test were used to evaluate how significantly a third of the bean’s stem affects the broadbean seed beetle’s egg-laying rate, the number of larval entrances in seeds and the number of individuals reached at least pupal stage. To assess the relationship between the egg-laying rate and the proportion of damaged seeds in harvested yield, Pearson’s correlation coefficient was calculated and regression analysis completed. In this case, the average number of eggs laid on the pods of each third of the stem during the peak laying period was used, as well as the proportion of infested seeds in each third of the stem from a sample collected a few days before...
harvest. The strength of correlation was estimated according to Green et al. (2000):

\[ |r| = 0.00–0.19 – \text{very weak correlation}; \]
\[ |r| = 0.20–0.39 – \text{weak correlation}; \]
\[ |r| = 0.40–0.59 – \text{moderate correlation}; \]
\[ |r| = 0.60–0.79 – \text{strong correlation}; \]
\[ |r| = 0.80–1.00 – \text{very strong correlation}. \]

In our study, the percentage between the larval entrance holes and the eggs laid on the pods was calculated. The number of eggs laid during the peak period was used for this calculation, but the number of larval entrance holes was taken from a sample of pods collected last in each field shortly before harvest. The last sample of pods from each field was also used to calculate the percentage between the number of larval entrances and the number of individuals reaching at least the pupal stage (pupae + young imagines + imago exit holes); to calculate the percentage of young individuals who have left seeds before harvest; and to calculate the total amount of yield damage done by the broadbean seed beetle.

Results

First overwintered broadbean seed beetle imagines on bean plants were observed at 274 GDD after sowing of beans in 2017; similarly, first imagines on bean plants were observed at 280 GDD in 2019; however, in 2018, first imagines were observed later, only at 351 GDD. The imagines were observed up until 881 GDD in 2017, in 2018 imagines were seen up until very late in the season, until 1422 GDD, the year 2019 was intermediate, with the last imagines seen at 1073 GDD. The highest observed number of broadbean seed beetle imagines per plant in 2017 was registered at 461 GDD, when 0.12 imagines per plant were seen in site B. In 2018, the highest number of imagines, 0.49 per plant, was registered in site B at 583 GDD. In 2019, the maximum registered number of imagines was 0.60 per plant, it took place in site B at 554 GDD. Overall, the highest numbers of the imagines per plant were observed between 250 and 750 GDD, observed numbers peaked at 500 GDD mark, but after 750 GDD mark relatively few imagines were seen (Figure 3).

The earliest observations of first eggs on pods were made in 2018, when the first broad bean beetle eggs were seen at 715 GDD. In 2017, first eggs were seen at 878 GDD, but in 2019 at 901 GDD. Egg observations continued up to 1513 GDD in 2018, and up to 1232 and 1584 GDD in 2017 and 2019, respectively. The maximum number of eggs per pod observed varied among the years considerably. In 2017, noticeably fewer eggs were observed, the maximum observed number was 5.15 eggs per pod, which was reached in site G at 878 GDD, which also happened to be the first observation of eggs in that year. In 2018, the highest observed average number of eggs per pod was 28.63, which happened in site B, at 1016 GDD. In 2019, a maximum of 22.25 eggs was observed in site C, at 1019 GDD. Overall, the number of observed eggs initially grew rapidly from 715 GDD, sharply peaked around 950 GDD mark, up to 1100 GDD mark it again decreased rapidly, but after that, the decrease was a lot more gradual (Figure 3). The seed beetle laid eggs most intensively on the pods of the lower third of the plant stems, but with the development of the pods of the middle and upmost thirds, the intensity of egg laying had decreased. Comparing the thirds of the stems, it is obvious that the eggs were significantly more laid on the pods of the lower third compared to the upmost one and in nine cases out of thirteen, also significantly more than on the middle one. The exception was the field of farm G in 2019, where the activity of the broadbean seed beetle was relatively low, and the maximal egg laying was observed on the pods of the middle third of plant stems. In this case, slightly less eggs were counted on the lower third’s pods, but significantly less – on the upmost pods. There were also cases where the intensity of egg laying did not differ significantly between the pods of the middle and upper third of the stem (Table 2).

The first larvae in seeds were observed starting from 923 GDD in 2019–1146 GDD in 2017. In 2018, the first larvae were observed at 954 GDD. In this year, the latest observation of larvae in seeds took place at 1887 GDD, but in 2017 and 2019, there were alive larvae found in seeds up to the last assessment at seed maturation at 2081 and 2171 GDD, respectively. However, the numbers of alive larvae in seeds by that point were very low – 0.015 and 0.002 larvae average per pod, respectively. The maximum observed number of larvae per pod increased eight-fold over the years of observation. In 2017, the highest number of larvae per pod was observed in site D at 1568 GDD– 0.46 larvae per pod. The highest observed number of larvae per pod in 2018 was 1.10; it took place in site B at 1117 GDD. In 2019, a maximum of 3.72 larvae per pod was found in site C, at 1146 GDD. Overall, the number of larvae per pod started off relatively high at the first successful observations, slightly increased up to 1200 GDD mark and from then on very gradually decreased until seed maturation when the observations were stopped approaching but not totally reaching zero.

According to egg-laying activity, the average number of larval entrances in the seeds was highest
in the lower third pods and lowest in the upper third pods of the stem, except for farm E field in 2018, when no significant difference in larval entrances between the thirds of stems was observed. The percentage reflecting the ratio of larval entrances to the maximum egg-laying rate was highly variable. In most fields, the average number of larval entrances per pod has been in the range of 17–98% compared to the maximum average number of eggs. However, in three cases (two fields in 2018 and one in 2019), the number of larval entrances to bean seeds was found to be higher than the average number of eggs counted on the pods during the peak egg-laying periods (Table 3).

The survival rate of the larvae and their ability to reach at least the developmental state of the pupa had been highly variable in the various bean sowings studied over the years. On average, 40%, 41% and 28% of the larvae in the bean seeds reached at least the pupal stage in the pods of the lower, middle and upmost thirds of the stem, respectively. However, no significant effect of the stem third on larval survival was

**Figure 3.** Phenology of different developmental stages of broadbean seed beetle in faba bean fields, according to the sum of GDD after bean sowing (filled circle, 2017; filled triangle, 2018; filled square, 2019).
observed ($p=0.20$). Assessing the average larval survival rate in each studied sowing, it was found that in 2018, the highest average survival was in the field of farm G, but the lowest – in the field of farm F. In 2019, the highest and the lowest larval survival was observed in the fields of farms C and A, respectively (Table 3).

The earliest broadbean seed beetle pupae were observed in 2018 at 1364 GDD. In 2017, the first pupae were observed at 1653 GDD but in 2019, at 1542 GDD. Pupae were observed until the bean harvest in all of the years, which was 2081, 2072 and 2171 GDD in 2017, 2018 and 2019, respectively. Numbers of pupae per pod at the end of the observation period ranged from 0.11 pupae per pod in 2017, which took place in site A to 0.01 pupae per pod in 2018 in site C. In 2019, at the end of the observation period, 0.04 pupae per pod in site B were found. The maximum numbers of pupae per pod were registered as 0.21 pupae per pod at 1827 GDD in site D in 2017, 0.28 pupae per pod at 1887 GDD in site B in 2018, and 0.64 pupae per pod at 1764 GDD in site D in 2019. Overall, the number of pupae showed a very symmetrical trend, gradually increasing from near zero at 1364 GDD, peaking at around 1800 GDD and steadily decreasing at about the same rate as the increase until the end of the observation period, where it did not reach zero (Figure 3).

The first broadbean seed beetle imagines within seed were observed at 1690 GDD in 2017, at 1539 GDD in 2018 and 1569 GDD in 2019. Imagines within seed were observed until the harvest of beans in all of the years of the research. The maximum registered number of imagines within seed per pod increased over the years of observation similar to the number of larvae, but not as dramatically. In 2017, a maximum of 0.15 imagines within seed per pod were registered at 1826 GDD in site B. In 2018, the maximum was

### Table 2. Maximum egg-laying rate of broadbean seed beetle in faba bean fields – the average number of eggs on one pod in each third of the plant stem

| Farm | Year | Lower | Middle | Upmost |
|------|------|-------|--------|--------|
| A    | 2019 | 12.03 | 4.67   | 1.58   |
| B    | 2018 | 34.02 | 31.98  | 19.81  |
| C    | 2018 | 18.68 | 12.20  | 10.58  |
| D    | 2018 | 3.27  | 0.18   | 0.07   |
| E    | 2018 | 15.72 | 6.92   | 1.03   |
| F    | 2018 | 0.62  | 0.58   | 0.18   |
| G    | 2018 | 11.55 | 9.70   | 7.55   |
| H    | 2018 | 5.55  | 4.86   | 0.20   |
| C    | 2019 | 1.22  | 0.77   | 0.22   |
| F    | 2019 | 0.45  | 0.00   | 0.00   |
| G    | 2019 | 4.11  | 2.23   | 0.97   |
| A    | 2019 | 3.22  | 2.01   | 0.22   |
| C    | 2019 | 0.98  | 0.36   | 0.31   |
| G    | 2019 | 4.45  | 5.14   | 0.56   |
| D    | 2018 | 7.35  | 6.76   | 5.05   |
| E    | 2019 | 3.22  | 3.01   | 2.10   |
| C    | 2018 | 0.98  | 0.36   | 0.31   |
| G    | 2019 | 8.45  | 7.44   | 0.56   |
| D    | 2018 | 1.11  | 0.60   | 0.41   |
| E    | 2019 | 7.56  | 6.86   | 2.56   |
| C    | 2018 | 0.24  | 0.17   | 0.15   |
| G    | 2019 | 1.69  | 0.90   | 0.29   |
| F    | 2018 | 0.45  | 0.11   | 0.09   |
| G    | 2019 | 2.02  | 0.62   | 0.24   |
| A    | 2018 | 1.30  | 1.01   | 0.51   |
| C    | 2019 | 1.04  | 0.98   | 0.62   |

### Table 3. The number of broadbean seed beetle larvae entrances and individuals, who had reached at least pupal stage before yield harvest, in bean seeds (both – the average per one faba bean pod in each third of the stem); for the larval entrances, their percentage to the maximum average number of eggs laid per pod is shown; for pupae + young imagines + exit holes of imagines, their percentage to the number of larval entrances is shown

| Farm | Year | Lower | Middle | Upmost |
|------|------|-------|--------|--------|
| A    | 2019 | 4.44  | 1.91   | 0.64   |
| B    | 2018 | 7.36  | 0.37   | 0.17   |
| C    | 2018 | 0.98  | 0.36   | 0.31   |
| D    | 2018 | 8.45  | 5.14   | 0.56   |
| E    | 2018 | 1.11  | 0.70   | 0.41   |
| F    | 2019 | 7.56  | 6.95   | 2.56   |
| G    | 2019 | 0.24  | 0.17   | 0.15   |
| A    | 2018 | 1.69  | 0.90   | 0.29   |
| C    | 2018 | 0.45  | 0.11   | 0.09   |
| D    | 2018 | 2.02  | 0.62   | 0.24   |
| E    | 2018 | 1.30  | 1.01   | 0.51   |

a, b and cSignificantly different values ($p<0.05$) within 1 year in one farm.
reached at 1834 GDD in site C, and it was 0.46 imagines within seed per pod. In 2019, in site D somewhat earlier than previous years, at 1649 GDD, a record of 0.56 imagines within seed per pod was reached. Overall, the number of imagines within seed per pod appeared to steadily increase throughout all observation period, albeit with some irregularities caused by extreme values obtained in some observations (Figure 3).

Broadbean seed beetle imagines, that had already left the seed, in form of empty exit holes in seeds, appeared the earliest in 2019 at 1649 GDD. In 2018, first imagines had left the seed at 1668 GDD, but in 2017, only at 1826 GDD. Seeds with empty exit holes could be found until the harvest of the yield in all years. However, in 2017, seeds with empty exit holes happened to be observed only until 2015 GDD, which is shortly before the end of the observation period at 2081 GDD, even though at 2081 GDD, there were still imagines within seed present. The highest registered number of empty exit holes in seeds also increased over the years of observation. In 2017, at 2015 GDD, in site B, it was 0.13 imagines, that had left the seed, per pod; in 2018, at 1702 GDD, in site C, it was 0.22 imagines and in 2019, at 2065 GDD, it was 0.31 imagines, that had left seed, per pod. Overall, there was a lack of clear trend in numbers of imagines that had left the seed observed per pod basis. There seemed to be a general increase in numbers, but they fluctuated a lot observation by observation.

The proportion of new imagines that have left seeds before harvest has varied from year to year in different sowings. In several cases, the exit holes of the new imagines were not found in the bean seeds at all, although part of the seeds were infested with the broadbean seed beetle. However, in two fields, more than 90% of the new imagines had already left the bean seeds before harvest, but in several other fields, this figure was close to 50% (Table 4).

In general, evaluating the harvested bean seed material, it must be concluded that the amount of damage caused by the broadbean seed beetle varied greatly in different fields in different years. The proportion of damaged seeds has varied from 1.8% (Farm F in 2018) to 74.3% (Farm D in 2019). The yield losses caused by the seed beetle within a single farm have also varied considerably from year to year. For example, in farm D, they have fluctuated from 34.1% in 2017, 8.9% in 2018 and the already mentioned more than 70% in 2019 (Table 4). It is clear that the amount of damaged seeds in the harvested yield is closely related to the egg-laying activity of the broadbean seed beetle when the beans have formed pods. There was a strong positive correlation between these two parameters ($r=0.621$; $p<.001$). However, this relationship is not linear but a polynomial. This is indicated by the coefficients of determination. In the case of a linear relation $R^2=0.386$, but in the case of the third-degree polynomial $R^2=0.712$. The percentage of damaged seeds increased in proportion to the average number of eggs laid on pods until this number reached 11–12

![Figure 4](image-url)
eggs per pod. However, with the further increase in egg laying, the proportion of damaged seeds did not increase significantly but remained at approximately the same level as it was when the average egg-laying rate was 11–12 eggs per pod (Figure 4).

Discussion
The use of GDD to describe the phenology of the broadbean seed beetle was chosen because it allows combining in one array the data obtained from different sowings of faba beans in different years. This parameter allows the phenology of the pest to be reflected according to the rate of development of the crop, regardless of the sowing time and the prevailing meteorological conditions. The second reason for using this parameter was that each field was sampled by another person during the study; therefore, it would not be objective to use, for example, the BBCH scale to determine the stage of plant development, as there would be too much room for interpretation and the resulting phenological data would be inaccurate. To make the results of the study easier to understand, further in this section of this article, instead of GDD, the appropriate plant development stage code from the BBCH scale or a description of a specific stage is used.

The first observations of broadbean seed beetle imagines on plants at the beginning of the growing season were made when the plants had reached growing stage 13–16 according to the BBCH scale (~3–4 weeks after sowing the beans). In Latvian conditions, this usually happened in the beginning of the third 10-day period of May, but if the sowing time of beans was relatively late, then the first broadbean seed beetle imagines could be observed in early June as, for example, in the field of the farm C in 2018. The highest densities of overwintered imagines were observed when the beans flowered intensively (second half of June), but in general, they were found on the plants even when the new generation of larvae was already detected in the bean seeds (first week of July). The highest imago density during bean flowering can be explained by the peculiarity of this species – sowings are initially colonised only by males, but females do so when the plants begin to flower (Medjdoub-Bensaad et al. 2007, 2015). The relatively shorter period of overwintered imagines activity in 2017 could be explained by the prevailing meteorological conditions of that year – the vegetation period was atypically cool and humid, and relatively rainy. In addition, the imagines recording method used may not be accurate enough to identify individuals in cases where the population density is very low, such as during the end period of imagines activity. Practical experience shows that the adults of the broadbean seed beetle are cautious, and when they feel the potential danger, they pretend to be dead and fall to the ground. Therefore, even if counting is done very carefully, it is not possible to list all the individuals. However, in general, we believe that the method used has well reflected the main trends – the beginning of the colonisation of bean fields, the peak period of overwintered imagines activity and the approximate end of the activity period.

The peak period for laying eggs coincided with the development stage of the beans, when they had pods in the lower third of the stem and flowers were still visible in the other thirds. In Latvian conditions, this has happened in the period from mid-June to the beginning of July. The sexual activity of female broadbean seed beetles is stimulated by the eating of field bean pollen, which is not only a source of nutrients but also contributes to the termination of individuals’ diapause. As a result, females become sexually active when they have access to the bean pods, which are the main egg-laying substrate (Tran and Huignard 1992), but the pods of the lower third of the stem develop first. In males, sexual activity is stimulated by an extension of the photoperiod to 16 light hours (Segers et al. 2021). These factors promote that, depending on environmental circumstances, such as the timing of the bean sowing and pace of development of the plants, which depends significantly on meteorological conditions, egg-laying may take place significantly earlier or later in various fields in various years. It means that if the growing season is relatively cool and the development of the beans is slow, individuals of the broadbean seed beetle are able to wait until the plants have reached the appropriate stage of development suitable for laying eggs.

The length of the egg-laying period in the various bean sowings we studied was mostly 4–5 weeks, but in some cases, the egg laying was observed for 3 or 6 weeks. This is in line with Hamani and Mefjdoub-Bensaad’s (2015) observations that the egg-laying period is about 5 weeks long, but is partly in line with other studies that have shown that the laying period can be as long as nine weeks (Medjdoub-Bensaad et al. 2007, 2015). Our study shows that the number of eggs laid on pods can vary greatly. This is likely to depend on the density of the seed beetle population in each particular field. In two studies carried out in Algeria, an average of 8.3 eggs (Medjdoub-Bensaad et al. 2007) and 6.4 eggs per pod (Medjdoub-Bensaad et al. 2015) were found during the peak of the egg-laying period. However, our observations show that on average more than 34 eggs can be laid on one pod (farm B in 2018).
The fact that eggs are laid significantly more on the pods of the lower third of the stem than on the pods of the middle and upper thirds is due to the fact that females are not choosy for the pods that have reached a particular stage of maturity. They lay the same amount of eggs on both older and younger pods (Hamani and Mefjdoub-Bensaad 2015; Medjdoub-Bensaad et al. 2007, 2015). Thus, as soon as the pods on the lower third of the stems are formed, the females begin to lay eggs on them en masse and continue to do so even when the pods of middle and upmost thirds are available.

The subsequent developmental phenology of the broadbean seed beetle’s individuals can no longer be strictly equated with the development rate of field beans, as the first larvae hatch and begin to develop relatively long before the last eggs are laid. Therefore, at a time when the faba beans have finished blossoming until harvest, the seeds may contain larvae, pupae and young imagines at the same time. Our study shows that circa one-half of the broadbean seed beetle’s individuals develops and leaves the bean seeds before harvest, but others remain in the seeds also after the harvest. This is in line with a number of other studies which have shown that the seed beetle develop, using one of two strategies. One strategy is to develop at a normal pace. As a result, the young imagines has developed and left bean seeds until the harvest. Individuals using this strategy hibernate somewhere in shelters found in the environment. The second strategy is a slowed-down or decelerated development, because of which the imagines develop completely in the harvested seeds, where they also overwinter (Medjdoub-Bensaad et al. 2015; Segers et al. 2021). The reasons for choosing a specific development strategy are not yet known.

In our study, the number of larval entrance holes in the seeds in most bean sowings has been lower than the number of eggs counted on the pods, which is logical because any insects have mortality during the egg phase. However, the percentage of larval entrance holes obtained by us in relation to the number of eggs laid on pods (Table 3) cannot yet be considered as a precise rate of egg mortality in the field conditions. This is also indicated by individual cases in our study when the number of larval entrance holes was more than 100% of the number of eggs counted on the pods during the peak of the egg-laying period (this was observed in three fields). Most likely, this phenomenon can be explained by the length of the egg-laying and embryonic development period, as well as the methodology used in our study. It has already been mentioned that the egg-laying period for broadbean seed beetle can last up to 9 weeks, but throughout this time, the eggs are laid on both new and older pods in similar amounts. In turn, embryonic development lasts 5–20 days, depending on the prevailing meteorological conditions (Boughdad 1994; Hamani and Mefjdoub-Bensaad 2015; Medjdoub-Bensaad et al. 2007).

Thus, it can be assumed that in cases where the density of the seed beetle population in the bean sowing is low, a correspondingly small amount of eggs will be observed on the pods every 7 days (our period for the egg-counting). Some of these eggs will develop successfully and the larvae will enter the seed, but the low-level egg laying will continue for a relatively long time, and from time to time, other larvae will enter the seed. Consequently, the total number of larval entrance holes in the seeds may eventually be higher than the number of eggs listed on the pods. We cannot offer any other explanation for this phenomenon. It is possible that under field conditions, the egg mortality rate could be determined by counting eggs once a day on marked pods, but the listed eggs should be marked each time so that they are not counted more than once. When the egg-laying period is over, the larval entrance holes must be counted in the seeds in the pods. However, for the time being, there is a need for discussion on how to technically carry out such a study, for example, how to mark laid eggs so that they are not injured and so that the marking does not interfere with the development of pods and hatched larvae.

The mortality of the seed beetle larvae in our studied sowings has been noticeably high. In all cases, shortly before harvest, there was on average less than one seed beetle individual per seed, which would have reached at least the pupal stage. Of course, in the fields where higher egg-laying activity was observed, the proportion of damaged seeds was also higher. However, a lower larval survival percentage was also observed in the same sowings. Not all causes of larval mortality are known yet, as the results of such studies are not available. Several studies on the pea seed beetle (Bruchus pisorum (Linnaeus, 1758)), which is close relative to the broadbean seed beetle, have also concluded that in seeds with a relatively large number of larval entrances, usually only one individual survives and develops up to the pupal stage. Several authors emphasise that cannibalism may be observed among larvae of this species in cases where the larvae meet with each other when making their tunnels in the seed (Grigokov 1960; Larson et al. 1938). Only III instar larval mortality is directly related to their density, but no such relationship is observed in other instars (Smith and Ward 1995). The mortality of other seed beetle species – Callosobruchus chinensis (Linnaeus, 1758) – larvae in legume seeds are affected by various physical and chemical parameters, such as seed moisture.
content, seed peal thickness, phenol and protein content etc. (Chakraborty and Mondal 2016). Broadbean seed beetle larvae in their IV instar of development, as well as pupae, tend to be parasitised by Braconidae wasps, which cause the death of part of the population (Medjdoub-Bensaad et al. 2015). The potential effect of various pathogens on larval survival should be also taken into account.

The results of our study outline the direction for further studies on how to practically control broadbean seed beetle’s populations in faba bean sowings. Our results show that even a relatively small number of eggs laid can mean excessive crop losses. According to the equation in Figure 4, during the maximum egg-laying period, 0.3 eggs per pod on average are resulting in 3% damaged yield what is the maximally allowed level in the market of Latvia. Therefore, the focus should be on limiting the presence and/or activity of females in sowings. In several of the farms studied, their owners used insecticides, but in most cases, this was done for a relatively long time before the beans flowered. It is now known that effective control of the seed beetle in this way is unlikely, as the density of the imago population was far from the peak at that time, and females, as mentioned above, have not yet started colonising the fields (Medjdoub-Bensaad et al. 2007, 2015). It would be important to develop effective measures that would prevent the invasion of broadbean seed beetles into faba bean sowings. The fact that something like this is possible is shown by the results of our study – in several fields where no plant protection products were used, the egg-laying activity of the seed beetle and the proportion of damaged yield has been very low. Thus, there are factors in the environment that may limit broadbean seed beetle populations, but these factors are not yet well understood. In cases when the seed beetles have nevertheless infested bean sowings, effective methods of limiting egg laying must be developed. It is likely that attention should be paid to the moment when the faba beans begin to flower.

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